



Hourly updated models: Rapid Refresh / HRRR review

NOAA ESRL GSD

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Rapid Refresh version 3

Scheduled implementation Q3 2015

- Upgrades: Thompson aerosol-aware MP, G-F cum. param., MYNN PBL, RUC LSM, sat. radiance BC, assim. mesonet, Vr, LTG
- RAPv3 improvement over RAPv2
Reduced warm season afternoon/evening low-level warm/dry bias. Improved upper-air / storm environmental fields

High-Resolution Rapid Refresh V2

Scheduled implementation Q3 2015

- Improved PBL/LSM/cloud physics
- Improved radar/PBL assimilation – radial wind, lightning added
- Improved storm forecasts from RAPv2/RAPv3 environment fields.



Rapid Refresh and HRRR NOAA hourly updated models

13km Rapid Refresh (RAP) (mesoscale)

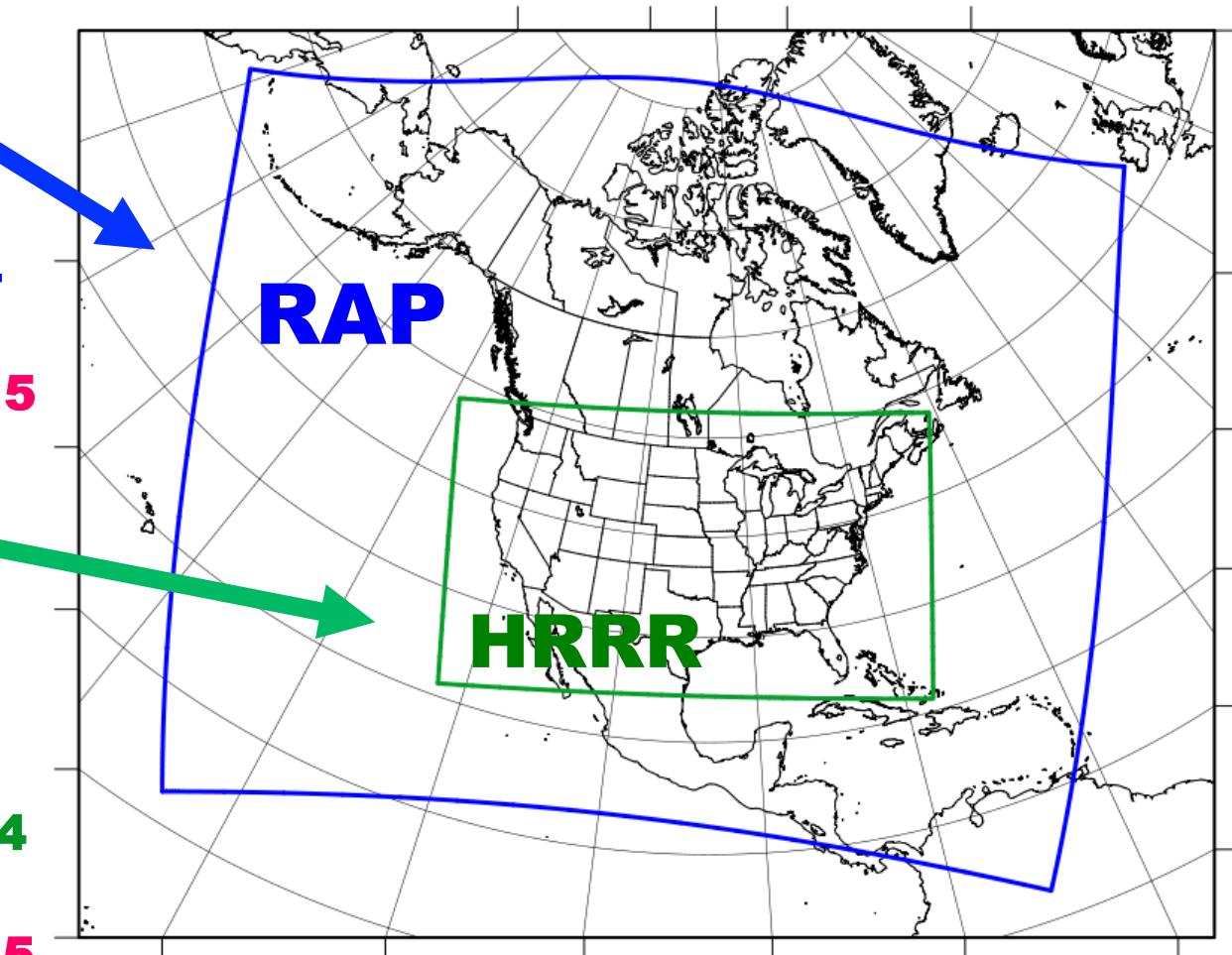
Version 2 – NCEP implement 25 Feb 2014

Version 3 – GSD Planned NCEP – Q3 2015

3km High Resolution Rapid Refresh (HRRR) (storm-scale)

Initial – NCEP implement 30 Sept 2014

Version 2 – GSD Planned NCEP – Q3 2015



Likely RAP version 3 changes

Model	Data Assimilation
<p>WRF-ARWv3.6+</p> <p>Physics changes:</p> <p>Grell-Freitas convective scheme</p> <p>Thompson MP -- Aerosol-aware</p> <p>MYNN PBL -- cloud/non-local mixing</p> <p>RUC LSM -- MODIS seasonal LAI -- improved wilting point</p> <p>Shallow cu parm w/rad feedback</p> <p>RRTMG radiation scheme</p> <p>Direct and diffuse GHI components</p>	<p>Merge with GSI trunk</p> <p>75% global ensemble BEC weight</p> <p>Radiance bias correction, channel selection, RARS data assimilation</p> <p>Radial velocity assimilation</p> <p>Mesonet assimilation</p> <p>Lightning assimilation</p> <p>Pseudo-PBL obs for temperature</p> <p>Improved 2m T, Td diagnostic</p> <p>Low-reflectivity precip building</p>

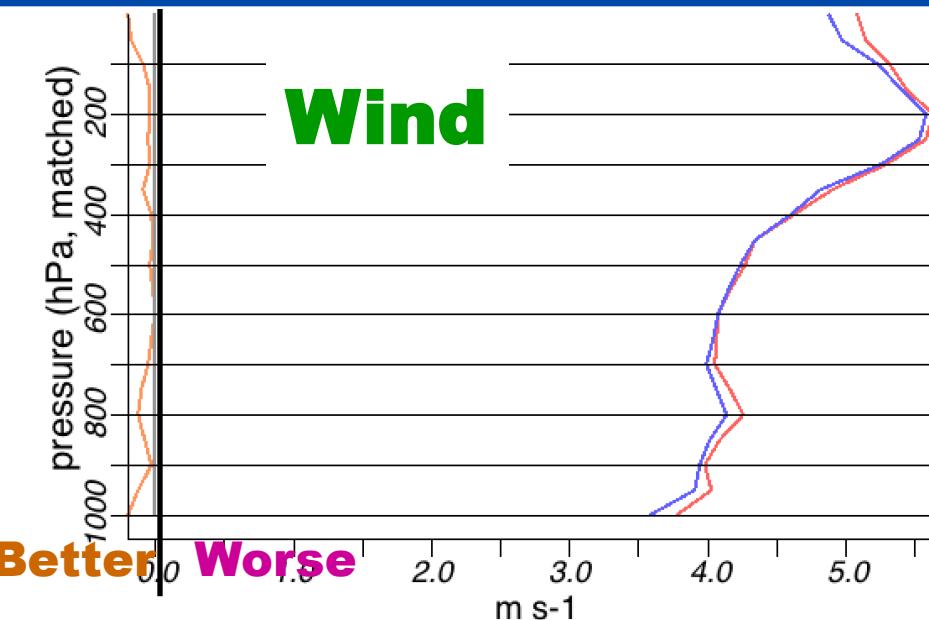


RAPv3: Observations used

Hourly Observation Type	Variables Observed	Observation Count
Rawinsonde	Temperature, Humidity, Wind, Pressure	120
Profiler – NOAA Network	Wind	~0
Profiler – 915 MHz	Wind, Virtual Temperature	20-30
Radar – VAD	Wind	125
Radar	Radial Velocity	125 radars
Radar reflectivity – CONUS	Rain, Snow, Hail	1,500,000
Lightning	(proxy reflectivity)	NLDN
Aircraft	Wind, Temperature	2,000 -15,000
Aircraft - WVSS	Humidity	0 - 800
Surface/METAR	Temperature, Moisture, Wind, Pressure, Clouds, Visibility, Weather	2200 - 2500
Surface/Mesonet	Temperature, Moisture, Wind	~5K-12K
Buoys/ships	Wind, Pressure	200 - 400
GOES AMVs	Wind	2000 - 4000
AMSU/HIRS/MHS	Radiances	5,000
GOES cloud-top press/temp	Cloud Top Height	100,000
GPS – Precipitable water	Humidity	260
WindSat Scatterometer	Winds	2,000 – 10,000



Upper-air: RAPv3 vs. oper RAPv2



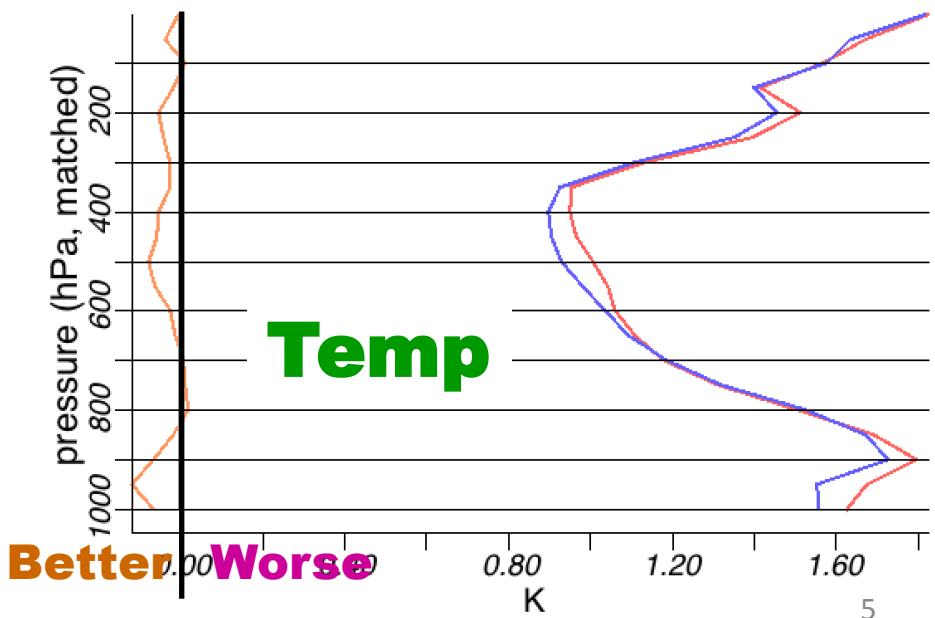
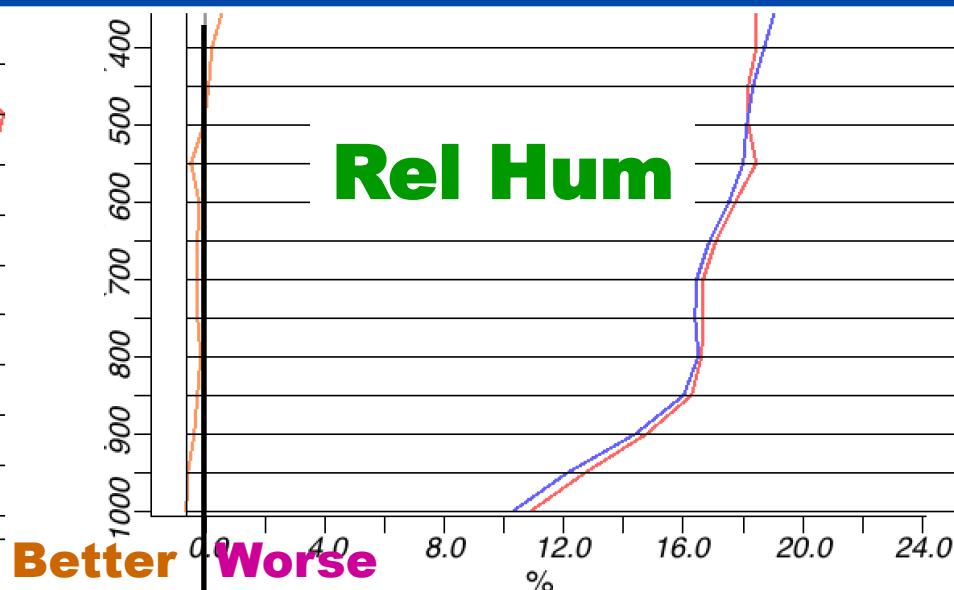
RAPv3

RAPv2

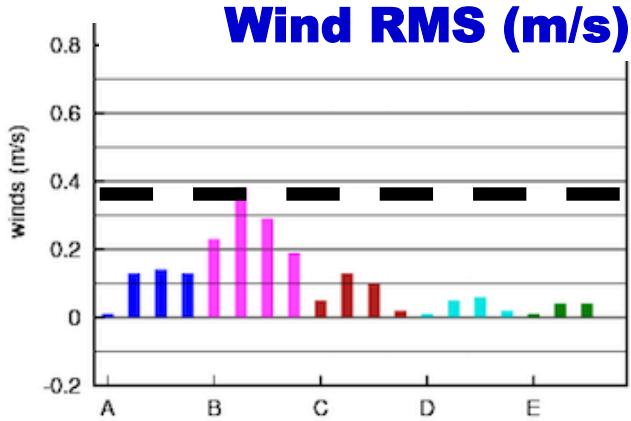
upper-air verification

+ 12 h forecast
RMS Error

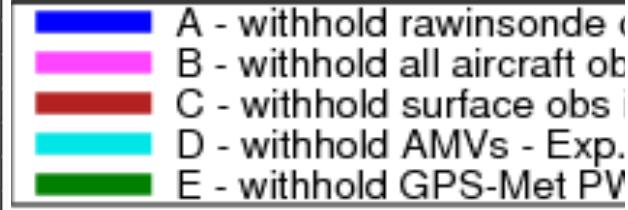
15 Sept – 1 Dec 2014



Wind RMS (m/s) [1000-1000 hPa]



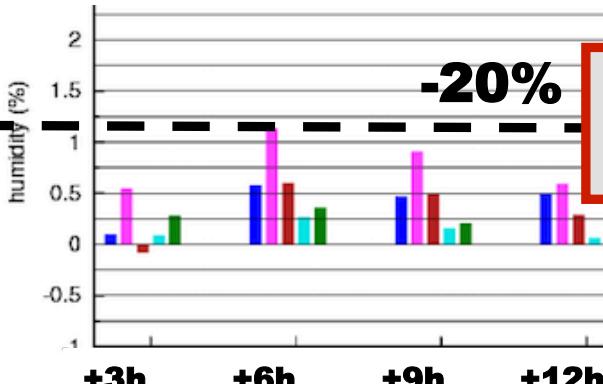
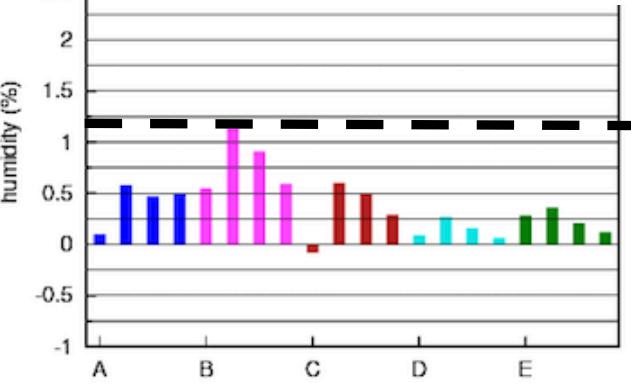
RAP 2013 obs impact



RAP data impact

- North America
- May 2013 experiments
- 12z and 00z combined

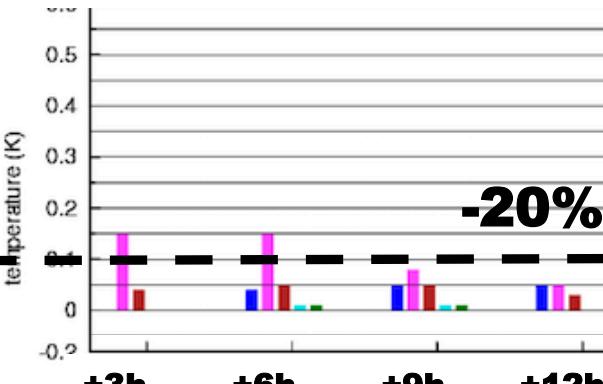
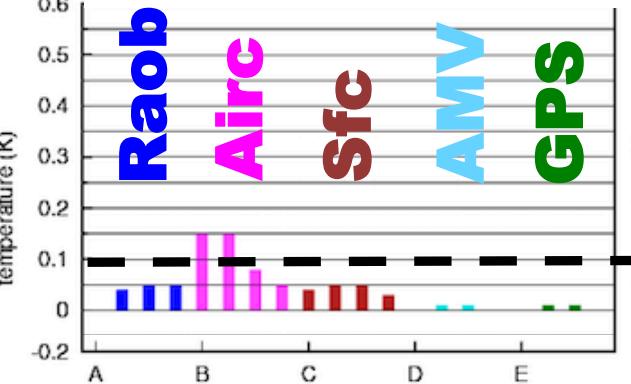
Relative Humidity RMS (%) [1000-400 hPa]



Normalize: 6h Fcst – 0h Anx

V – 1.8 m/s, RH – 6%, T – 0.5K

Temperature RMS (K) [1000-100 hPa]



Aircraft – largest impact

wind/RH/temp – all have up to 20% reduction forecast error, especially 6h-9h fcsts

Following in importance:

**Raob, Surface,
GPS-Met, AMVs**



NCEP RAPv2 and HRRR 2014

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	758 x 567	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly - RAP (no-cycle)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.4.1+	GSI Hybrid 3D- VAR/Ensemble	13-km DFI	RRTM/ Goddard	Thompson v3.4.1	G3 + Shallow	MYNN	RUC 9-lev
HRRR	WRF-ARW v3.4.1+	GSI 3D-VAR	3-km 15-min LH	RRTM/ Goddard	Thompson v3.4.1	None	MYNN	RUC 9-lev

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6 th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5 th /5 th	Positive- Definite	w-Rayleigh 0.2	Yes 0.12	10 min	MODIS Fractional	0.01 K/s	60 s
HRRR	5 th /5 th	Positive- Definite	w-Rayleigh 0.2	No	5 min	MODIS Fractional	0.07 K/s	20 s



NCEP RAPv3 and HRRRv2 2015

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	758 x 567	13 km	50	10 mb	GFS	Hourly (cycled)
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Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.6.1+	GSI Hybrid 3D- VAR/Ensemble	13-km DFI	RRTMG/ RRTMG	Thompson – aerosol-aware v3.6.1	GF – v3.6.1	MYNN v3.6.1+	RUC 9-lev v3.6.1+
HRRR	WRF-ARW V3.6.1+	GSI 3D-VAR/ Ensemble	3-km 15-min LH	RRTMG/ RRTMG	Thompson – Aerosol-aware v3.6.1	None	MYNN	RUC 9-lev v3.6.1+

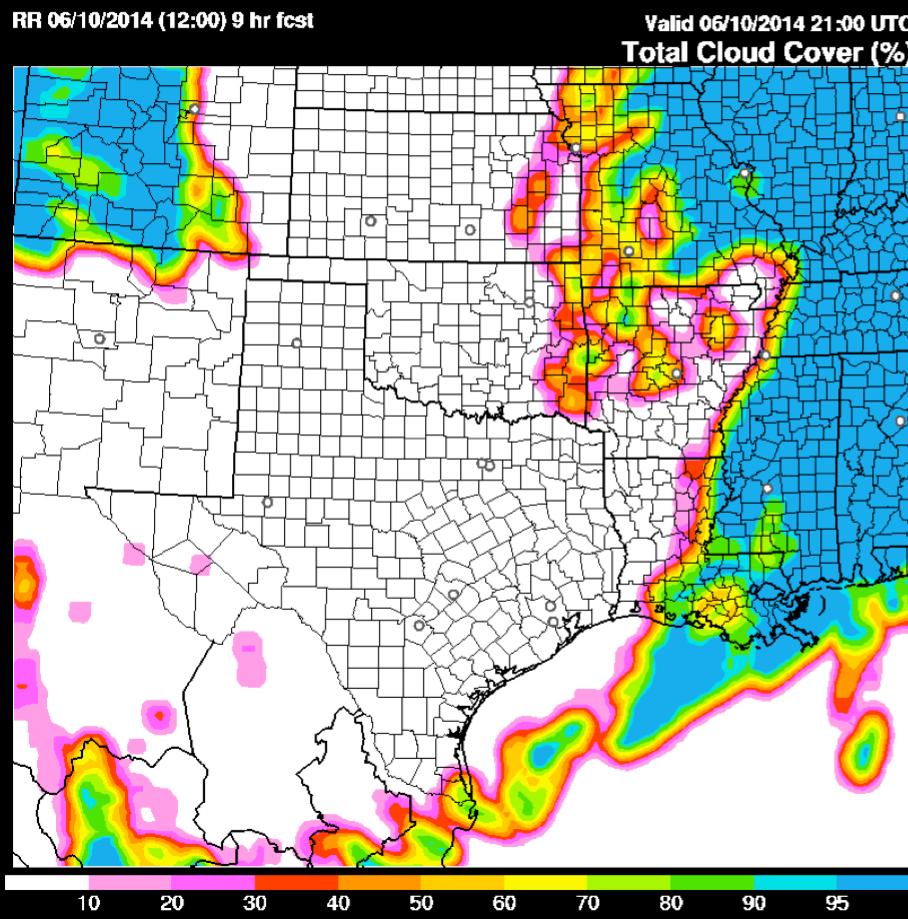
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NCEP RAPv3/HRRRv2-2015 Changes

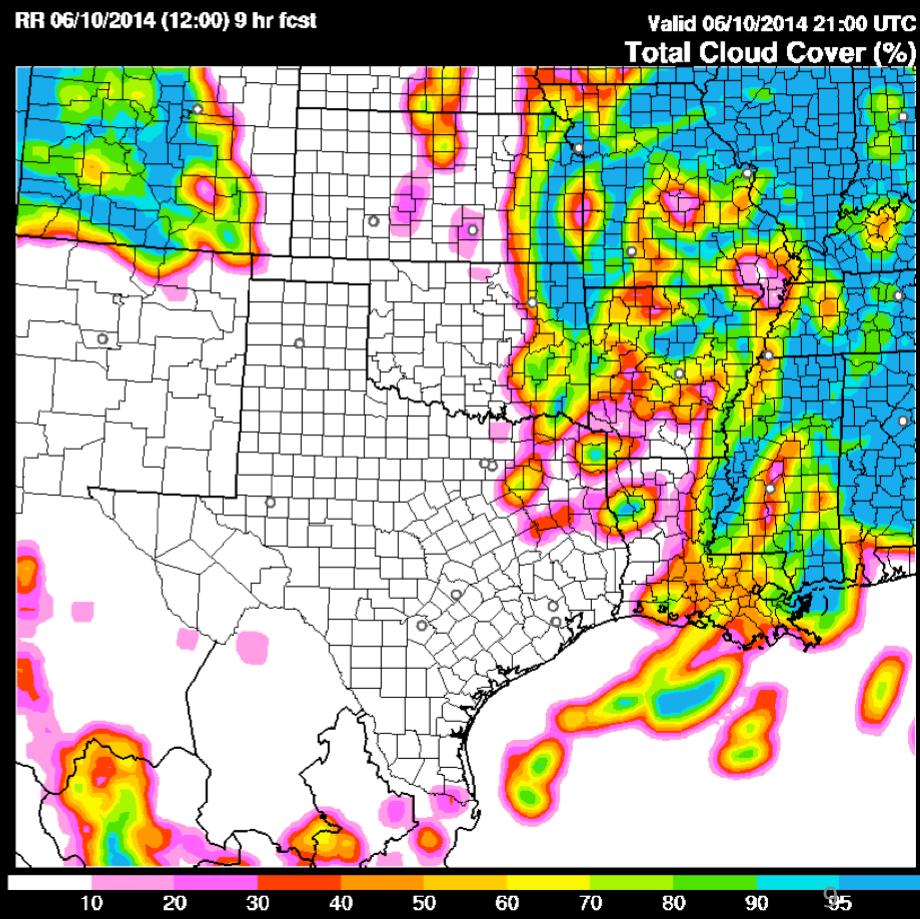
Use of forecast aerosol fields
to have prognostic cloud-
condensation nuclei (CCN).

WRFv3.5.1 aerosol unaware



Example: RAP cold-start tests
without/with aerosol-aware
cloud microphysics

WRFv3.6 Aerosol-aware





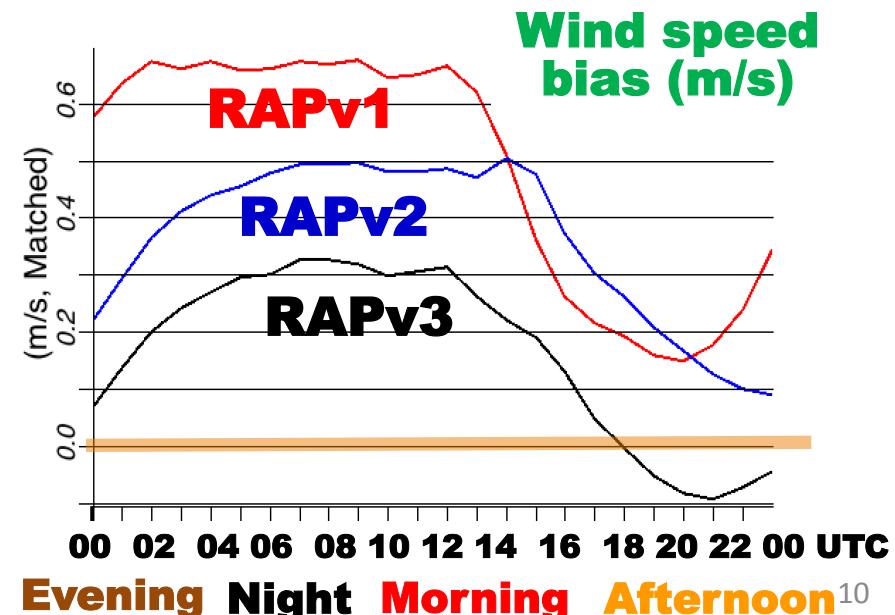
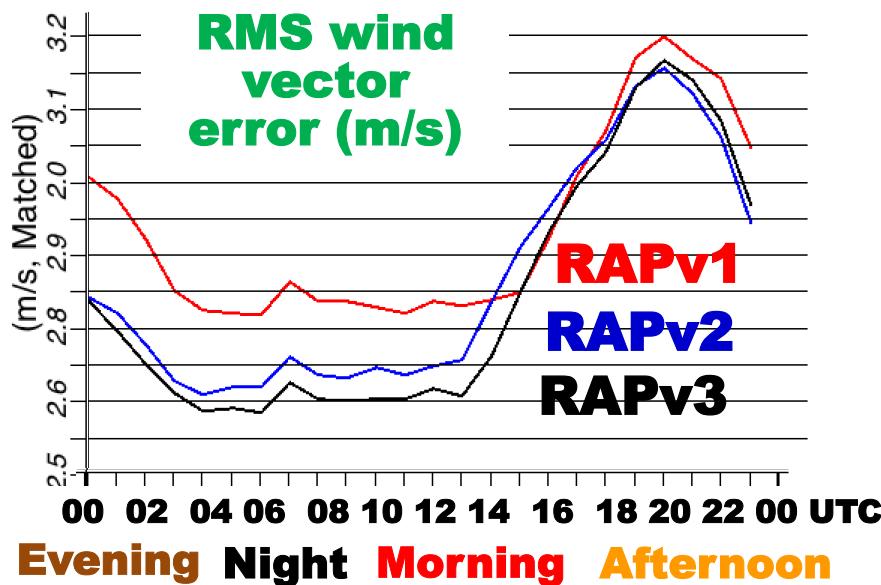
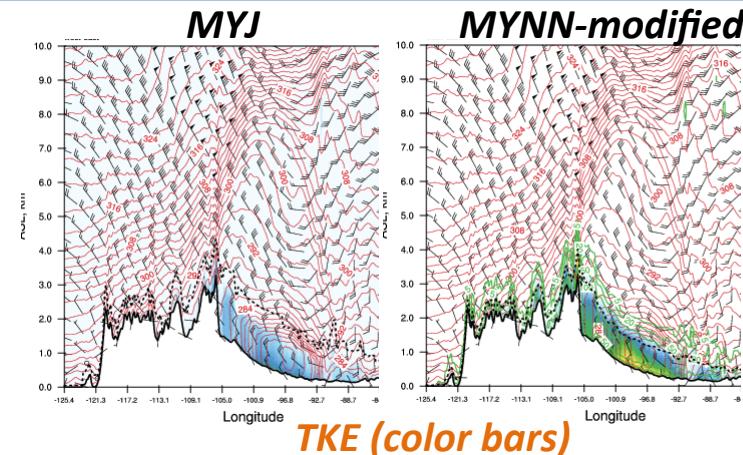
RAP / HRRR use of MYNN PBL scheme

First implemented with RAPv2 / HRRR 2013 –
better convection, wind forecasts

Improved mixing length formulations to
flexibly change behavior across the stability spectrum

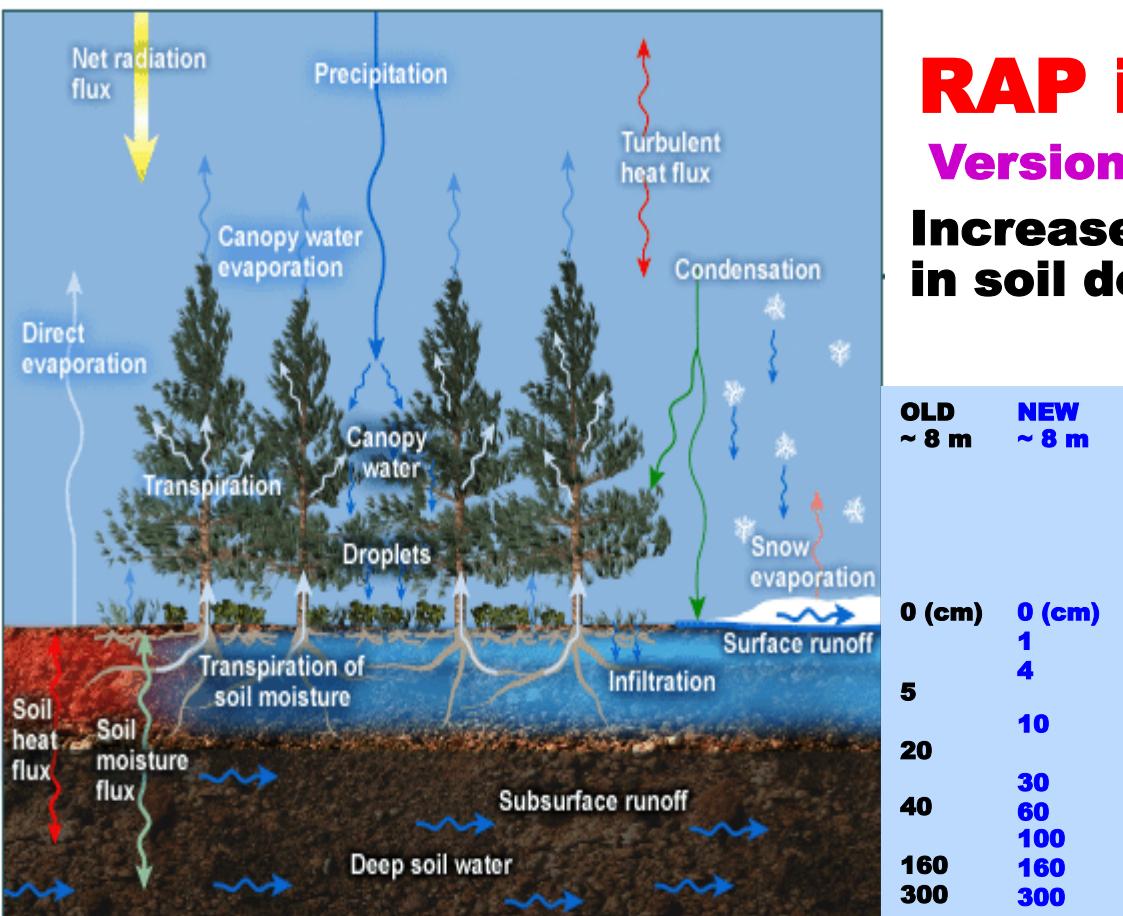
Improved surface layer scheme (customization to PBL)

Further enhancements for RAP v3 / HRRR v2 -- cloud mixing,
refined closure constants, coupling to different shallow cu schemes





Updates to RUC Land Surface Model



Thinner soil layer in energy / moisture budgets
Potential for increased near-surface diurnal cycle
Reduced warm bias at night, cold bias in day

RAP improvements Version 2

**Increased number of levels
in soil domain – 9 levels**

- Increased roughness Z_0 for forests, cropland, urban
- New formulation to compute **effective roughness length $Z_{0\text{eff}}$** in the grid box (exponential)

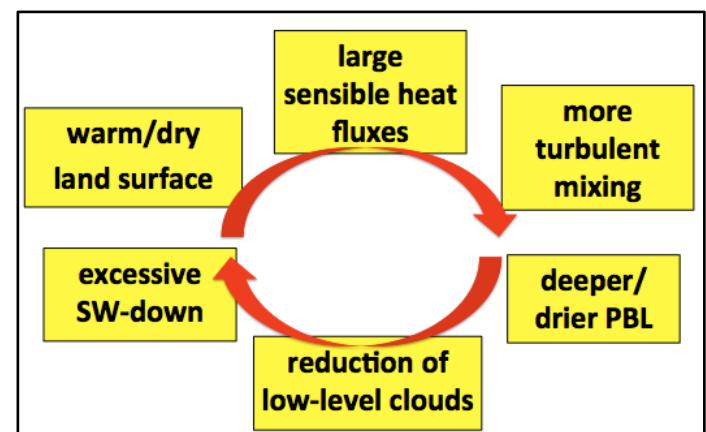
Version 3 (partial list)

- **Seasonal variations of Z_0** for MODIS cropland category
- **Seasonal variations of LAI** based on the current vegetation fraction and variability of this parameter for different vegetation types



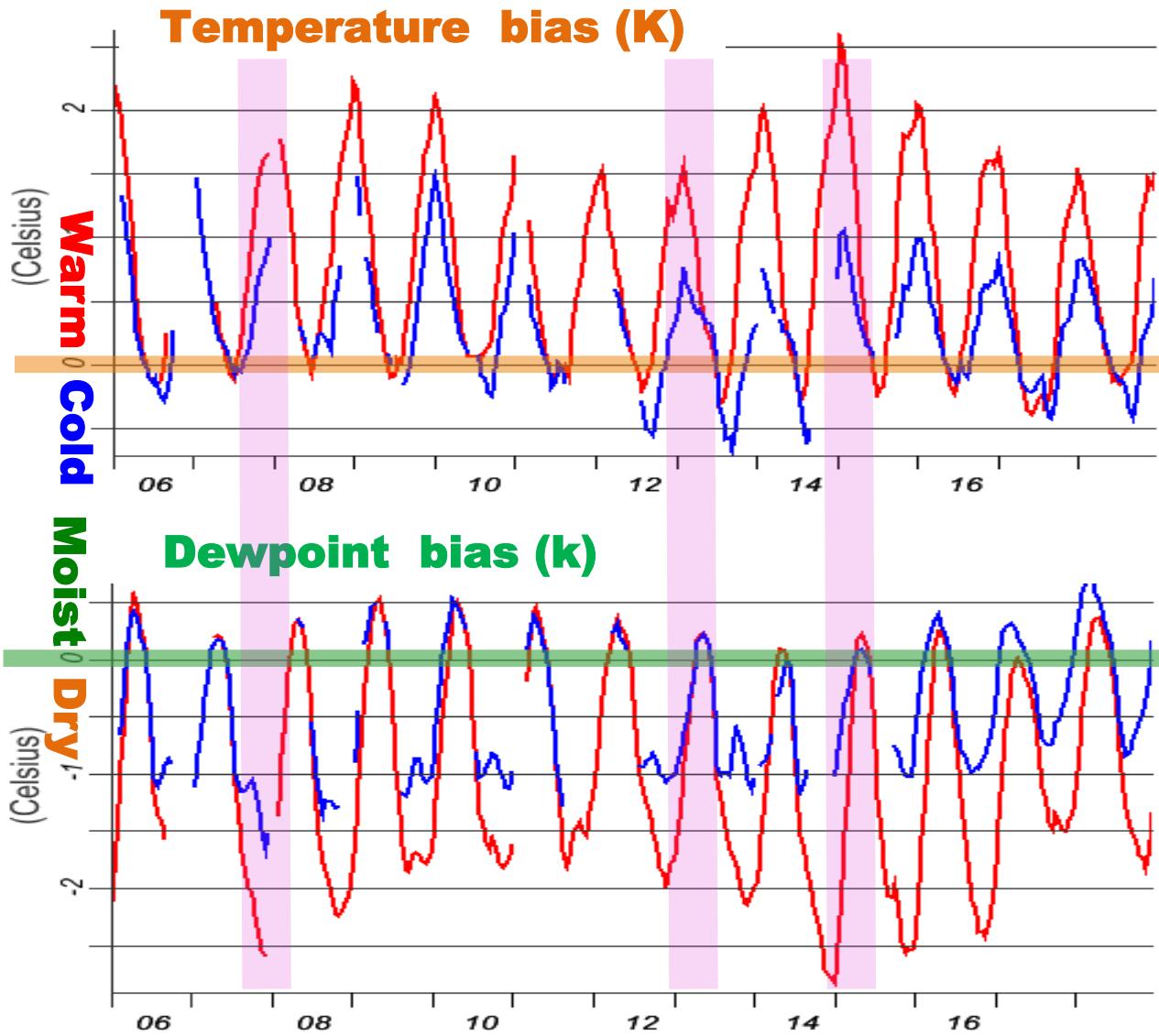
Physics updates to reduce warm / dry bias

- **Grell–Freitas “scale-aware” shallow cumulus (subgrid-scale)**
 - Accounts for **nonlocal** mixing of heat & water vapor from condensed (non-precipitating) subgrid plumes
 - “Scale-aware” mass flux scheme
 - Produces **subgrid** cloud water & ice
 - **coupled to radiation**
- **MYNN boundary-layer cloud fraction (subgrid-scale)**
 - Function of local and PBL-mean RH, surface heat flux, resolution
 - Activates in absence of resolved / parameterized cloud fraction in column
 - Diagnoses **subgrid** cloud water & ice
 - (specifically for radiation coupling)**
- **RUC-LSM**
 - **Reduced wilting points**
 - **Maintain cropland at wilting point**





Testing RAPv3 LSM Changes



NCEP RAPv2
GSD test RAPv3

8 Aug. 2014

Reduced
wilting point

13 Aug. 2014

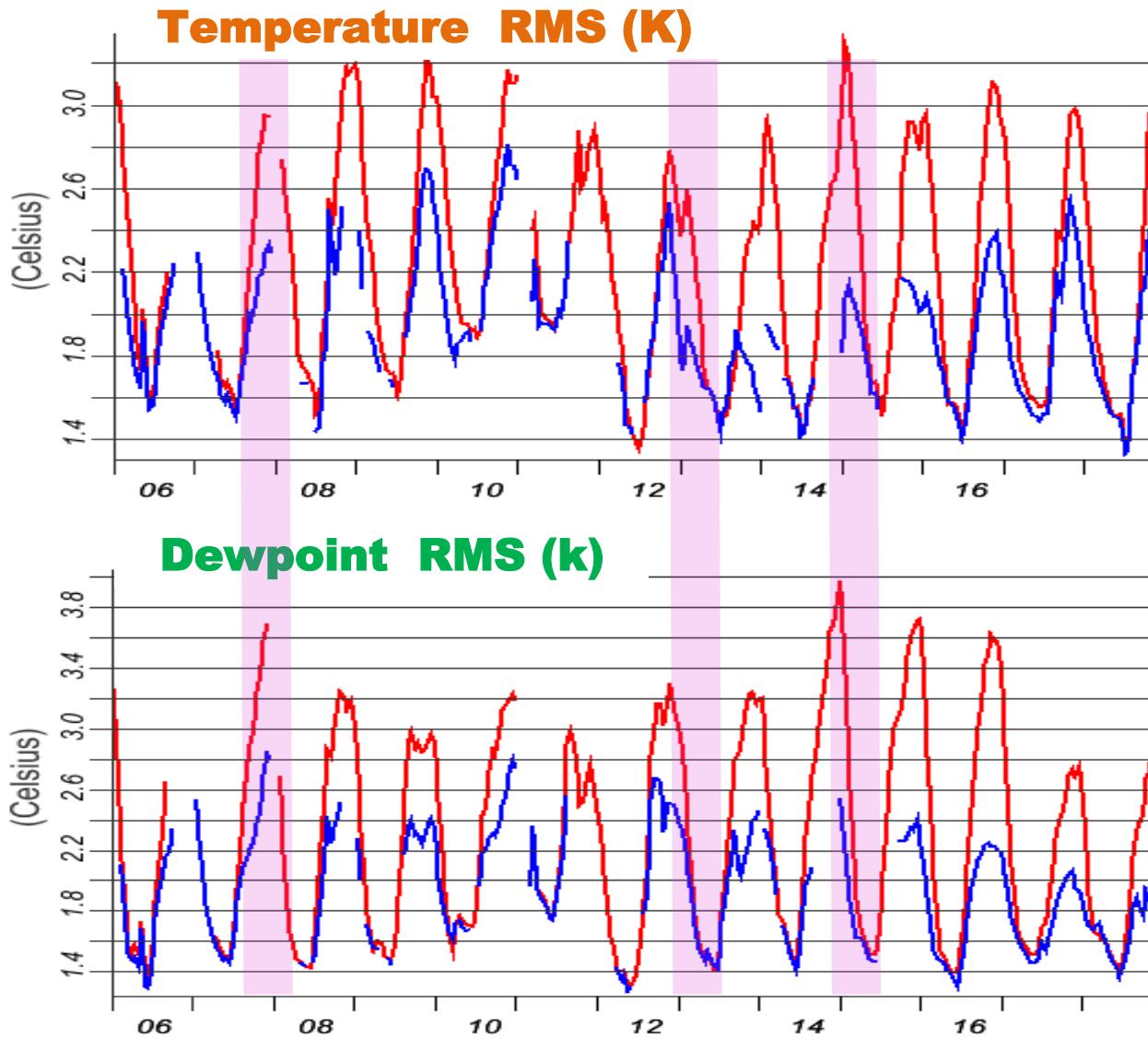
Change for
cropland soil
moisture

15 Aug. 2014

Q2 diagnostics



Testing RAPv3 LSM Changes



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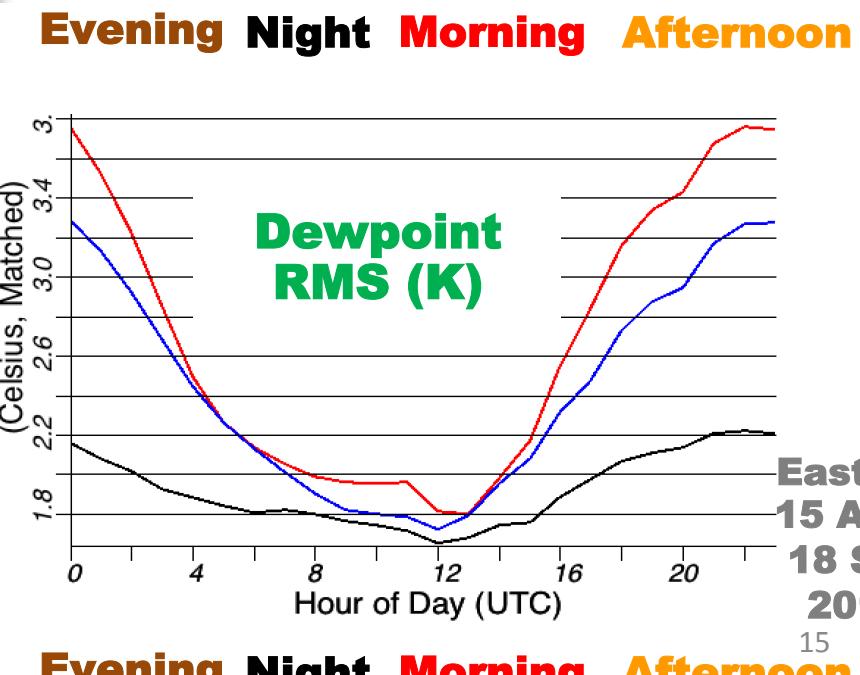
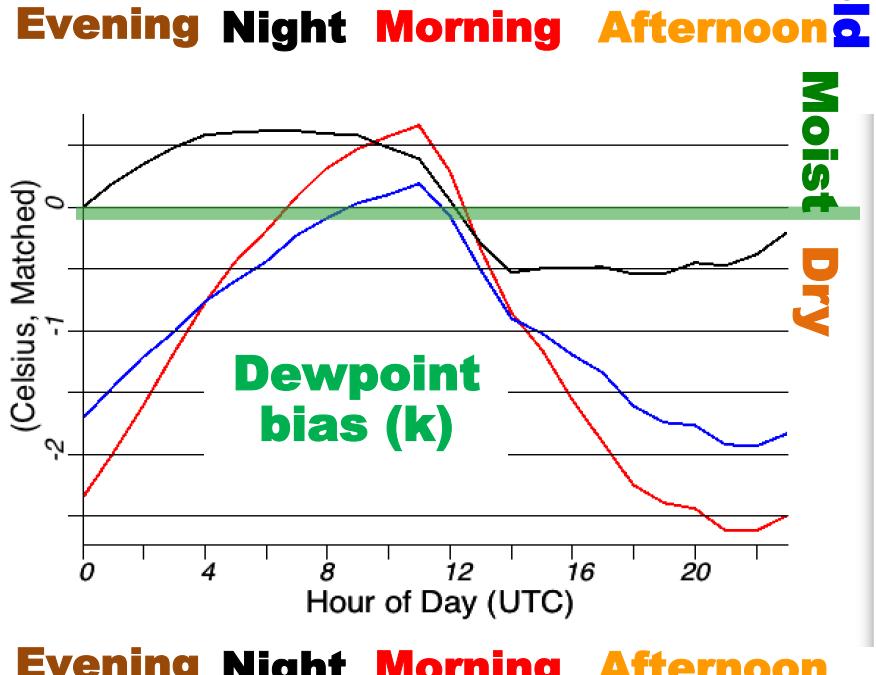
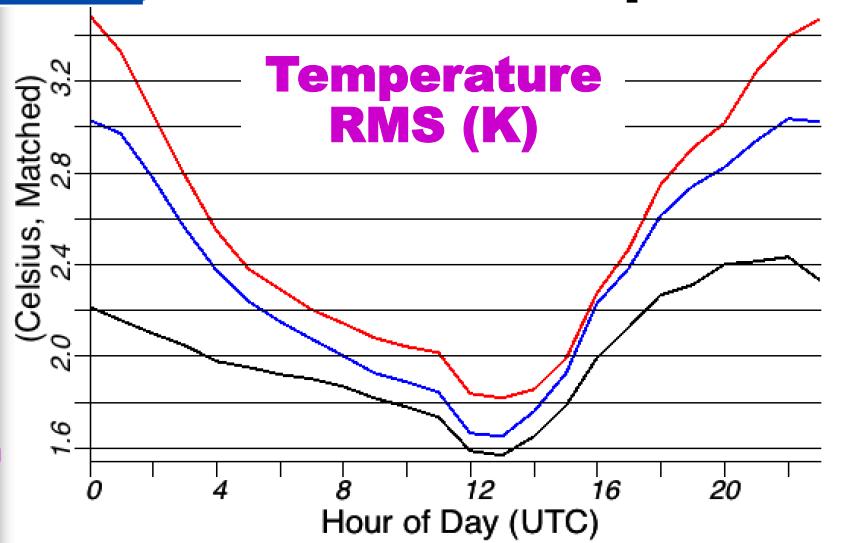
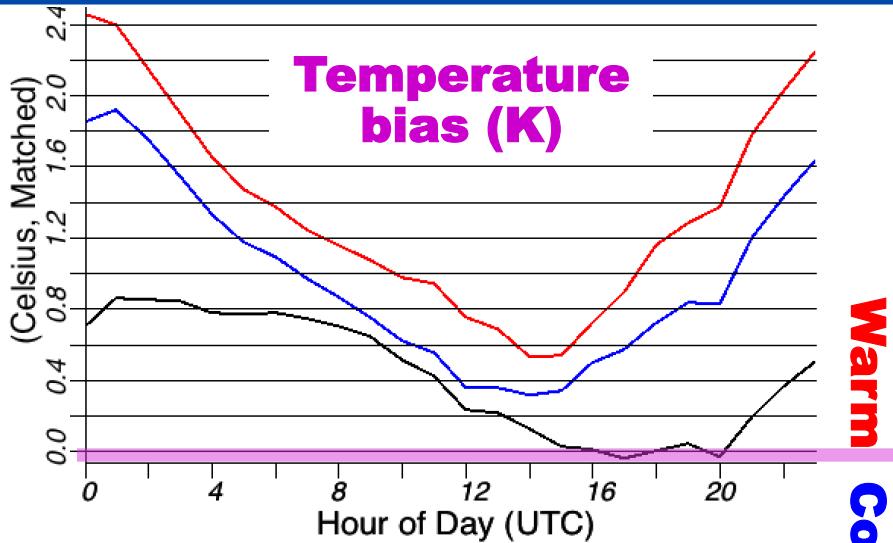
15 Aug. 2014

Q2 diagnostics

Rapid Refresh

Surface verification

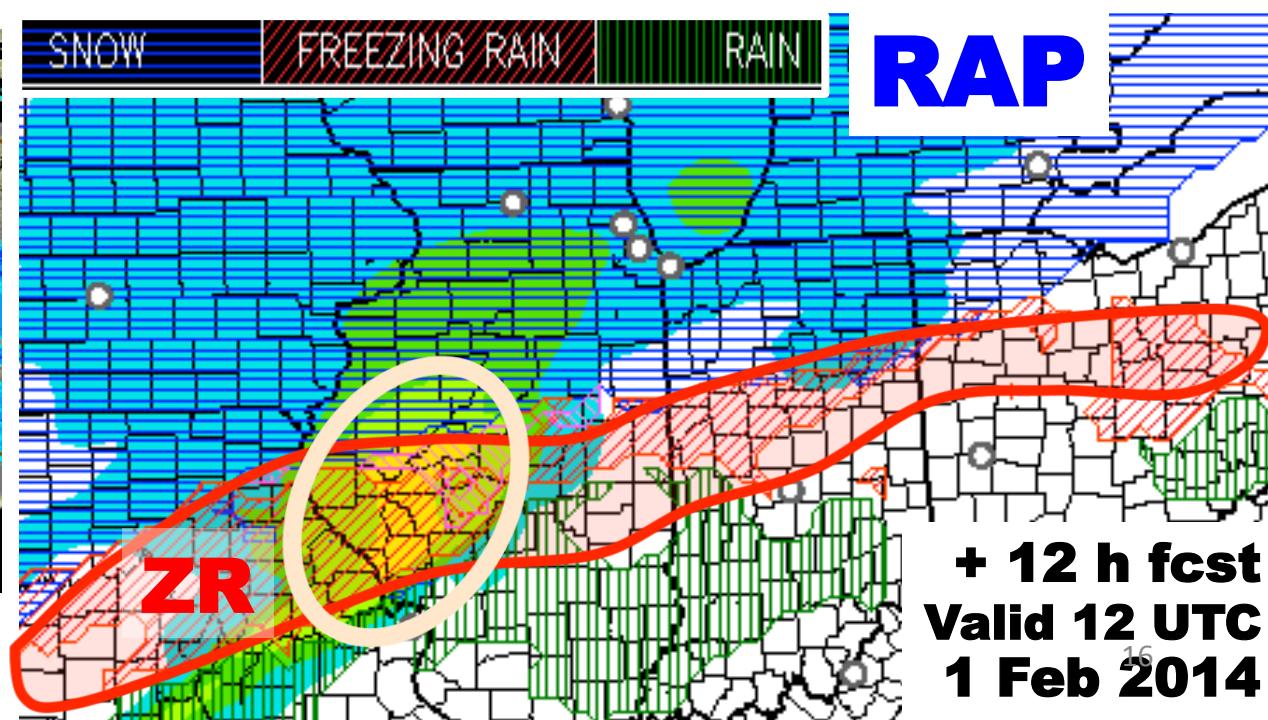
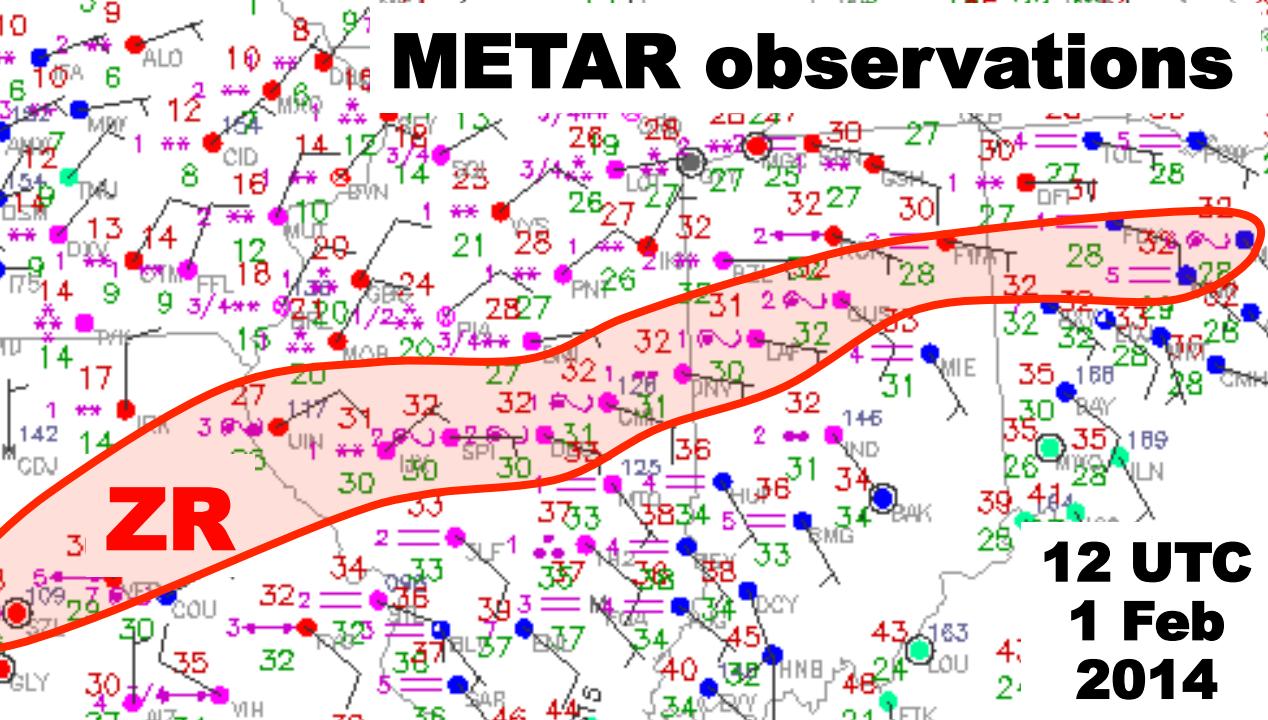
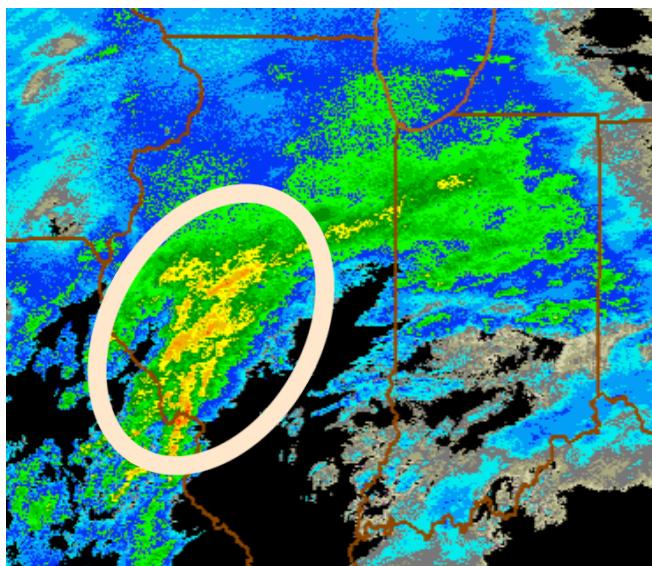
NCEP OPER RAPv2
GSD 2014 RAP R/T
GSD RAPv3 pre-NCEP



RAP

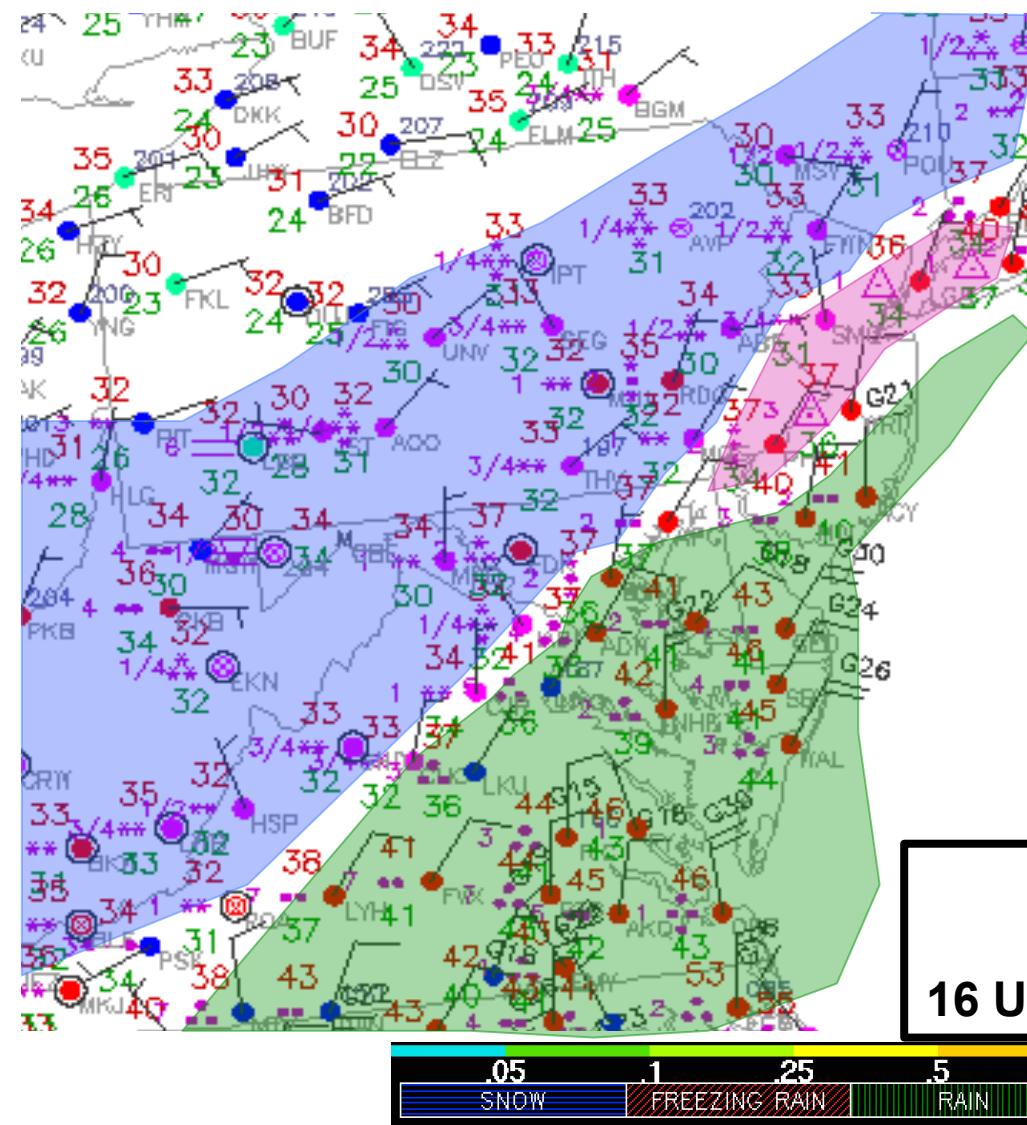
Sample mesoscale precipitation type and intensity

Radar obs

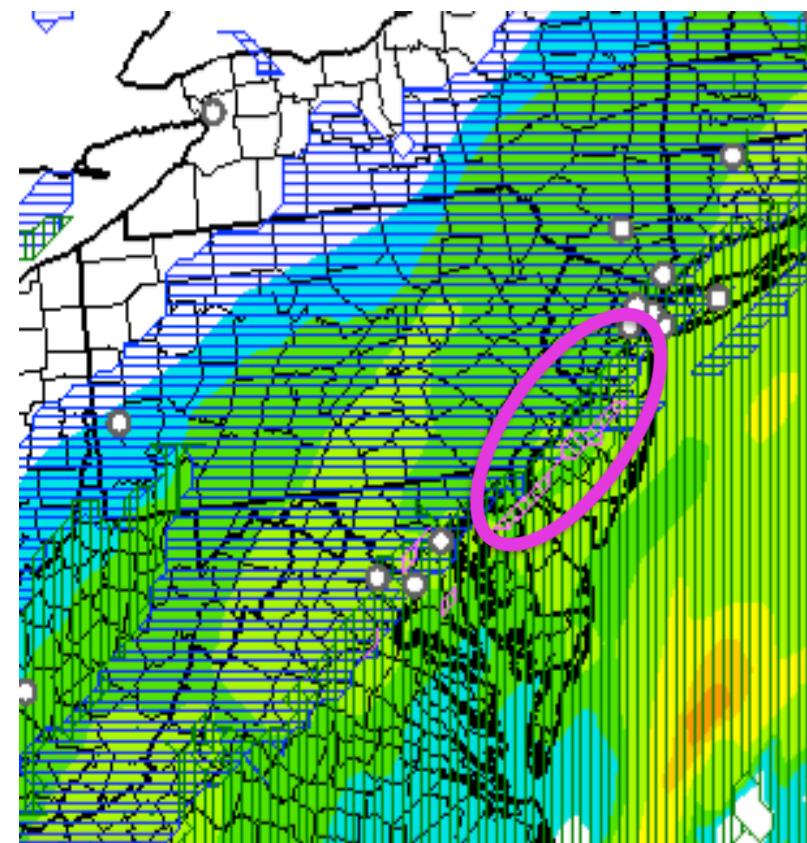




Improved RAP Precip Type



RAPX
18 hr Fcst
16 UTC 26 Nov 2014



RAP resolves
narrow IP band
(improved
diagnostic)



Summary: RAPv3 vs. RAPv2

Winds -- Consistent RAPv3 improvement for both upper-air and surface, for all seasons

Temperature – Reduced low-level warm bias for warm season afternoon / evening. Improved upper-level temperature forecasts

Moisture – Reduced low-level dry bias for warm season afternoon / evening. Improved upper-level relative humidity forecast

Precipitation – Slight improvement, reduced low thresh high bias / increased high thresh low bias

Rapid Refresh and HRRR NOAA hourly updated models

13km Rapid Refresh (RAP)

Version 2 -- NCEP
implement 25 Feb 2014

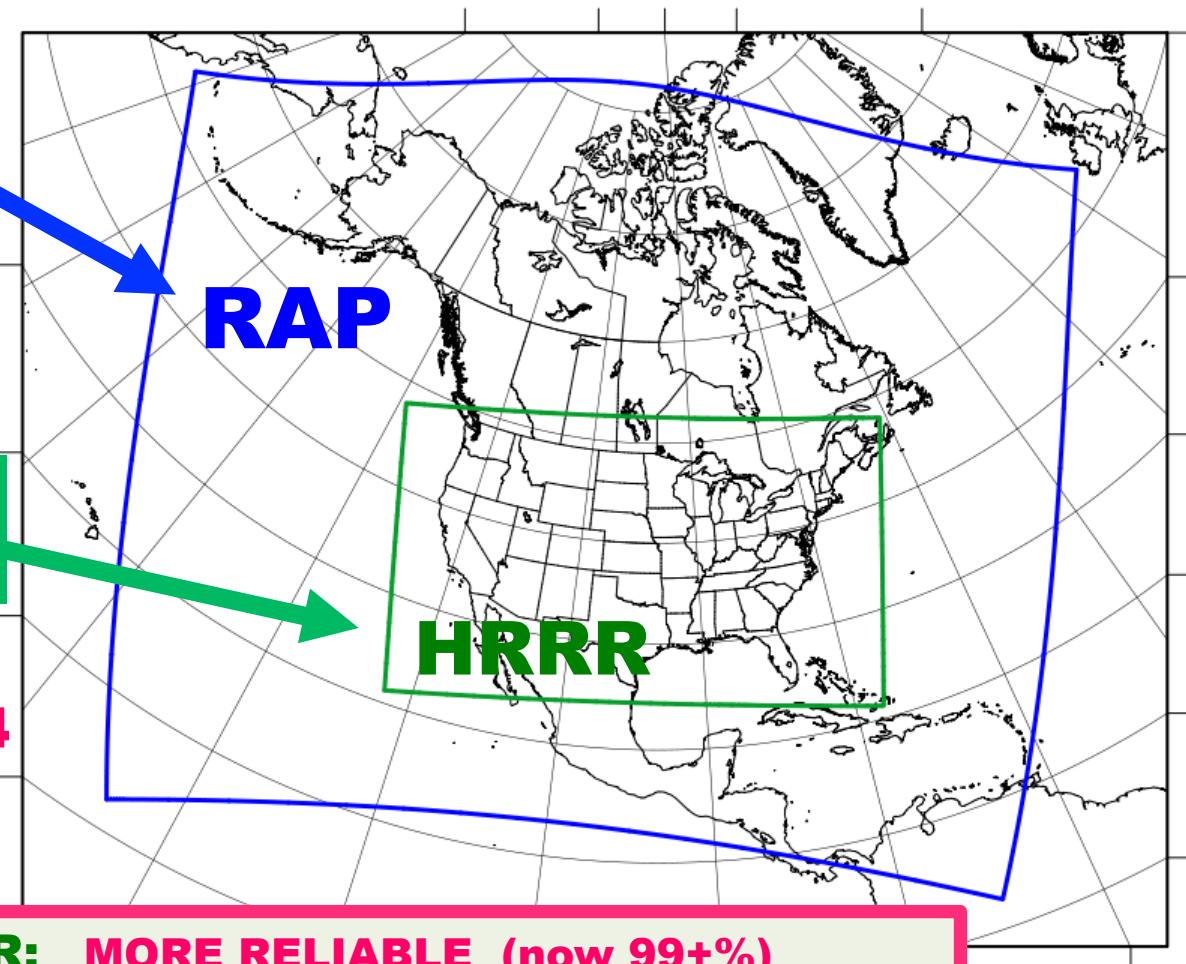
Version 3 - GSD
Planned NCEP -- 2015

3km High Resolution Rapid Refresh (HRRR)

Initial - NCEP
implement 30 Sept 2014

Version 2 - GSD
Planned NCEP --2015

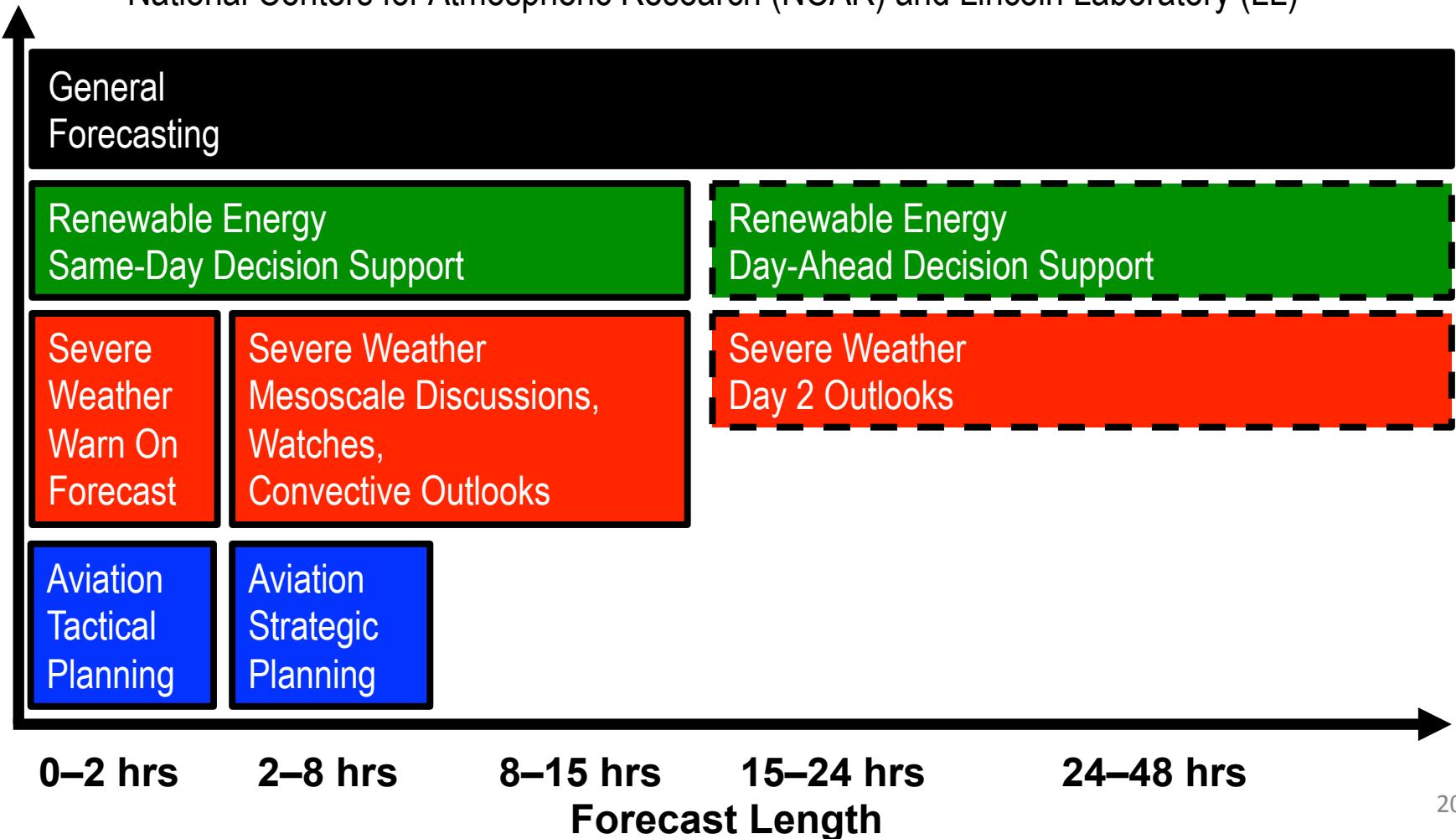
GSD →NCEP HRRR: MORE RELIABLE (now 99+%)
AVAILABLE SOONER (1h fcst by +50 min, 15h fcst by +1:30



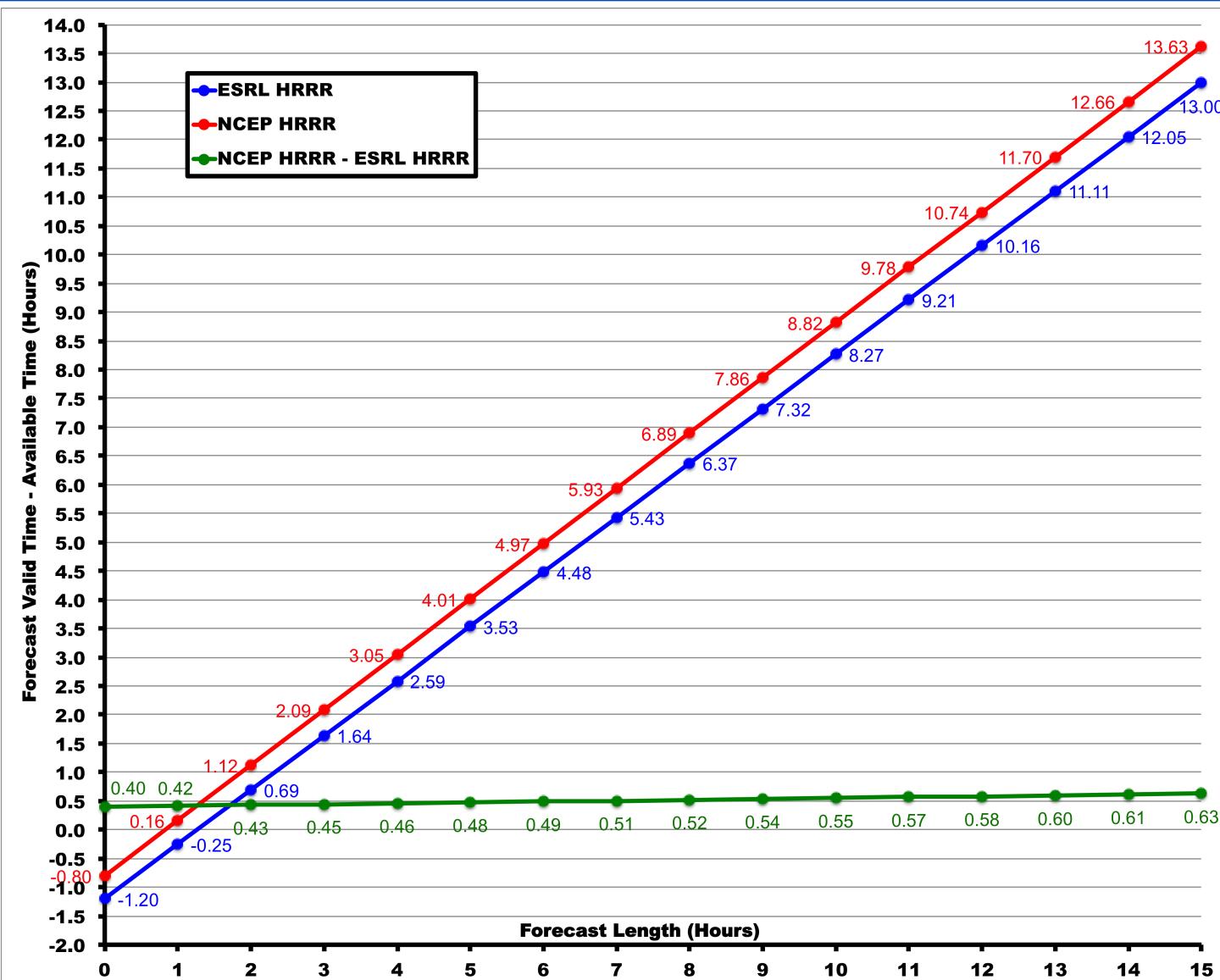


HRRR Users and Applications

Example: National Weather Service including Storm and Weather Prediction Centers (SPC & WPC)
Aviation Weather Center (AWC) and FAA Command Center
National Severe Storms Laboratory (NSSL) and Air Resources Laboratory (ARL)
National Centers for Atmospheric Research (NCAR) and Lincoln Laboratory (LL)



HRRR Forecast Latency

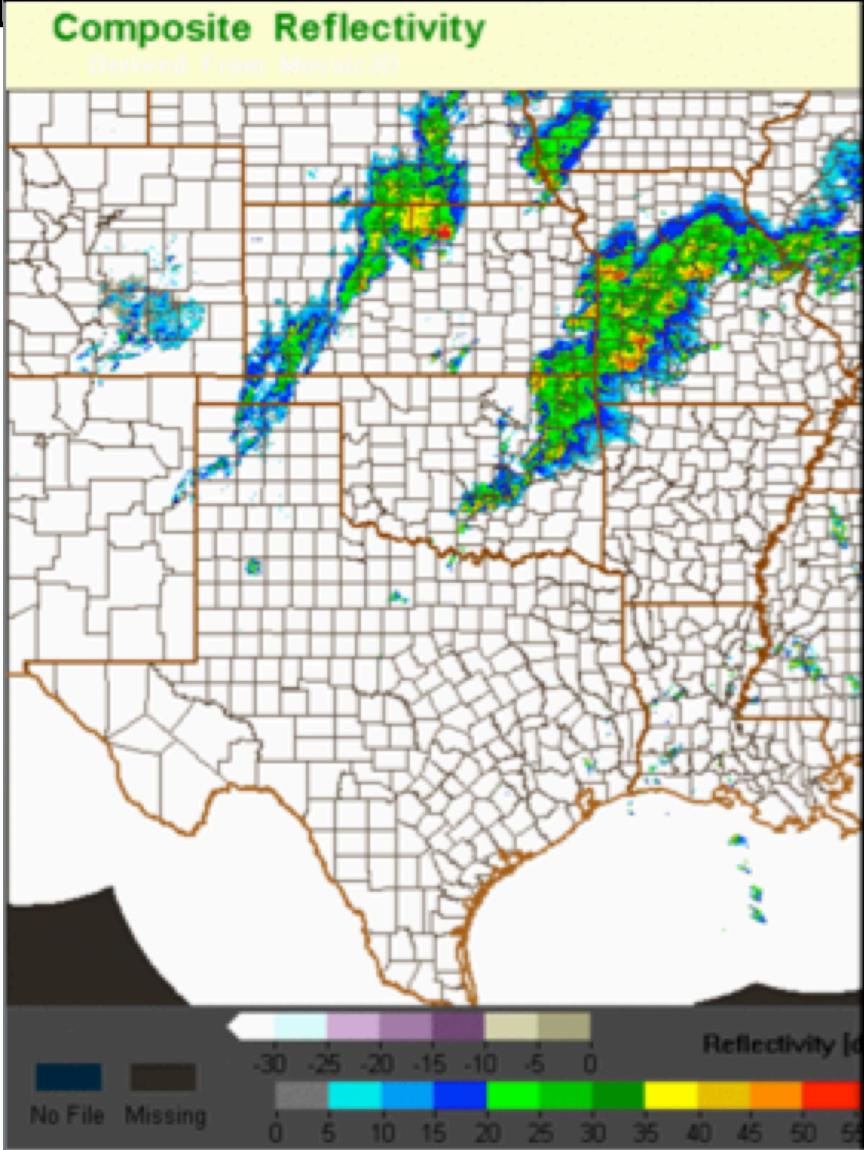


By the end of forecast, operational HRRR available on average ~36 min earlier than experimental HRRR

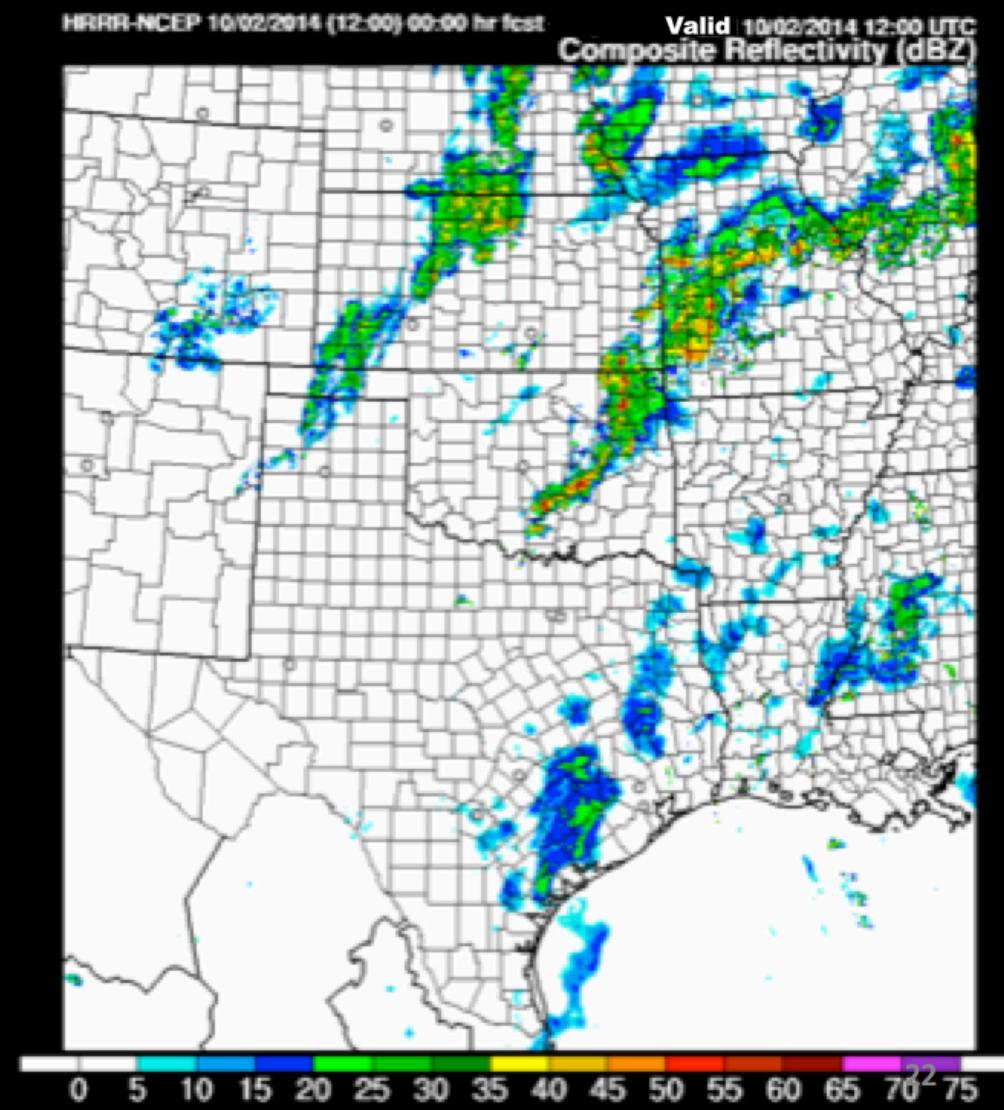


HRRR NCEP Implementation

Reflectivity Observations



Operational HRRR 12 UTC 02 Oct 2014





Candidate RAPv3/HRRRV2 Changes

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HRRR (3 km)	<p>WRF-ARWv3.6+ incl. physics changes</p> <p>Physics changes:</p> <p>Thompson MP - Aerosol-aware</p> <p>MYNN PBL -- cloud/non-loc mixing</p> <p>RUC LSM -- MODIS seasonal LAI</p> <p>-- Reduced wilting point</p> <p>Shallow cu parm w/rad feedback</p> <p>RRTMG radiation scheme</p> <p>Direct and diffuse GHI components</p> <p>Numerics changes:</p> <p>6th order diffusion in flat terrain</p>	Merge with GSI trunk 3-km hybrid assimilation Hydrostatic rebalance after analysis Radial velocity assimilation Mesonet assimilation Pseudo-PBL obs for temperature Improved 2m Temp/Dewpoint Background Estimate Low-reflectivity precip building Full cloud/precip hydrometeor assim



NCEP RAPv2 and HRRRV1

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NCEP RAPv3 and HRRRV2

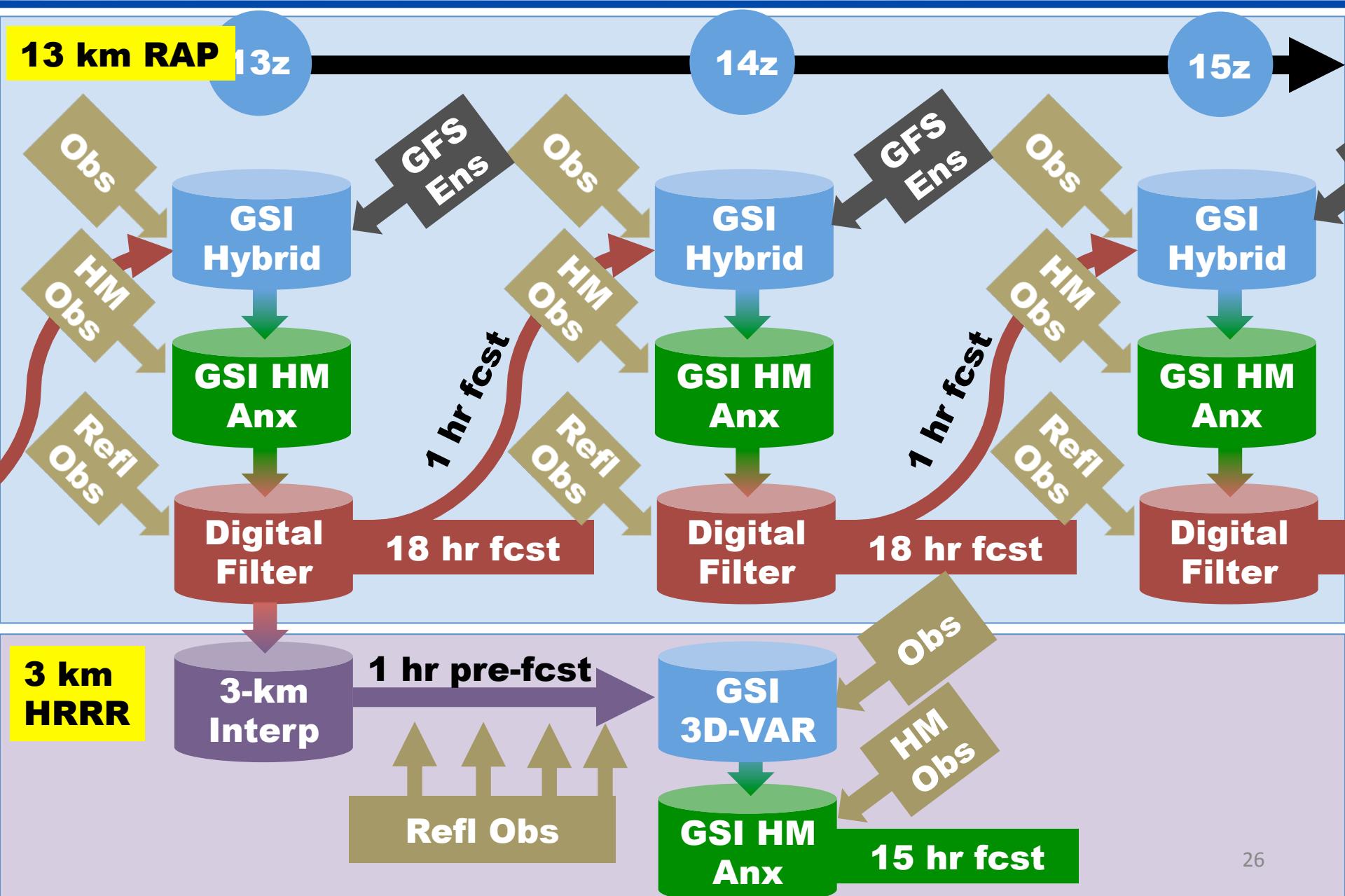
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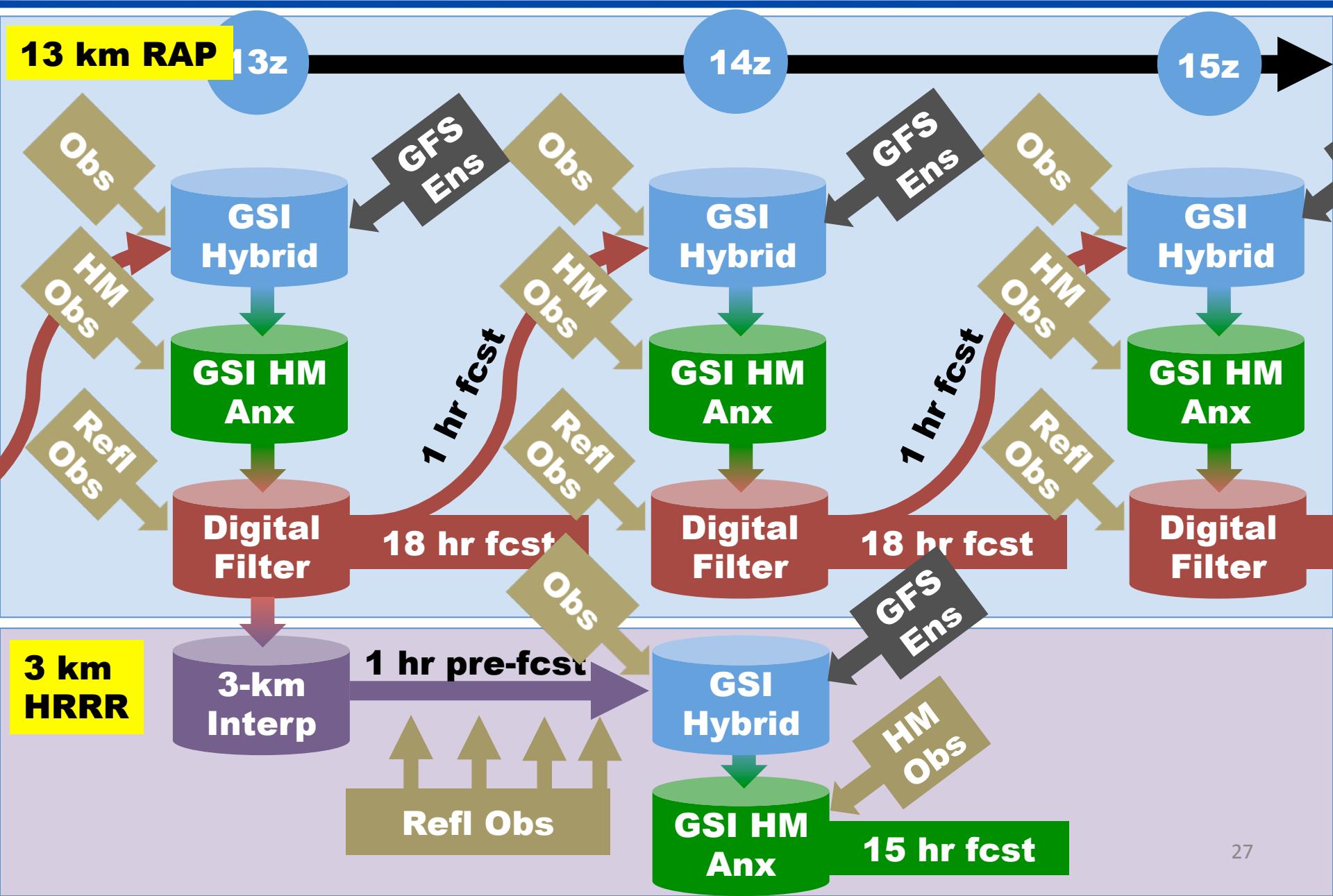


HRRRv1 Initialization from RAPv2



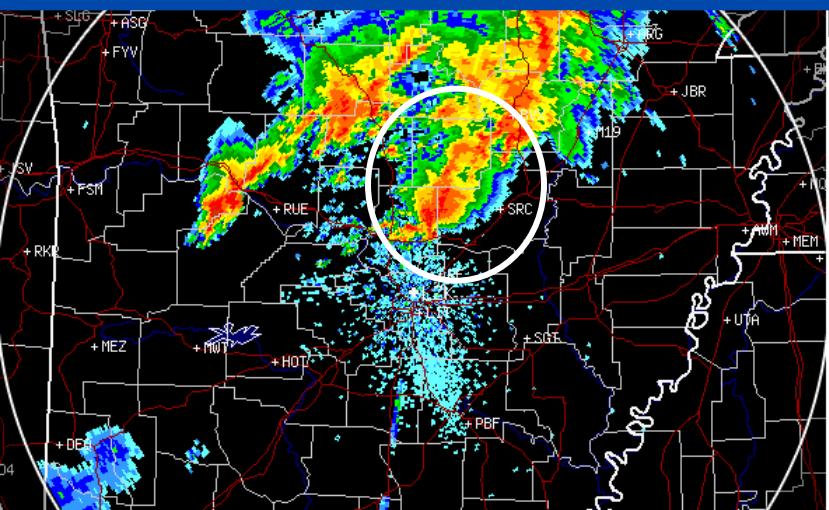


HRRRv2 Initialization from RAPv3



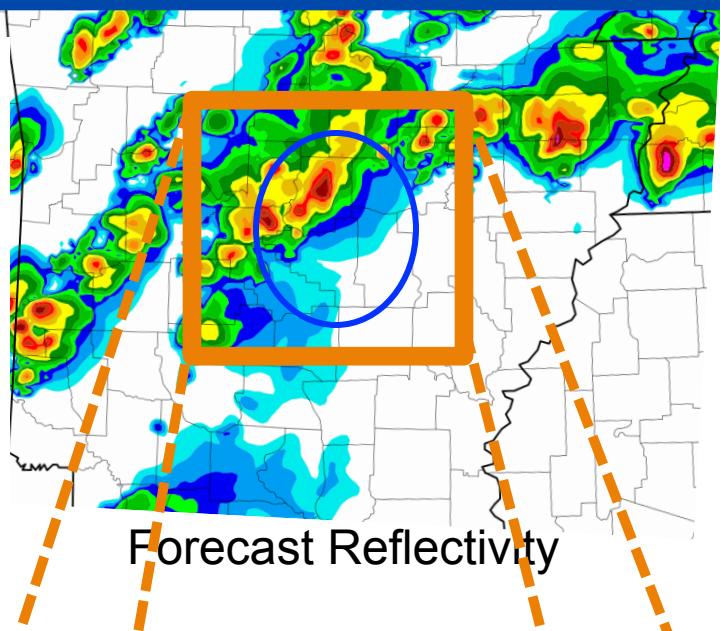


HRRR Supercell Case 27 April 2014



Observed Reflectivity

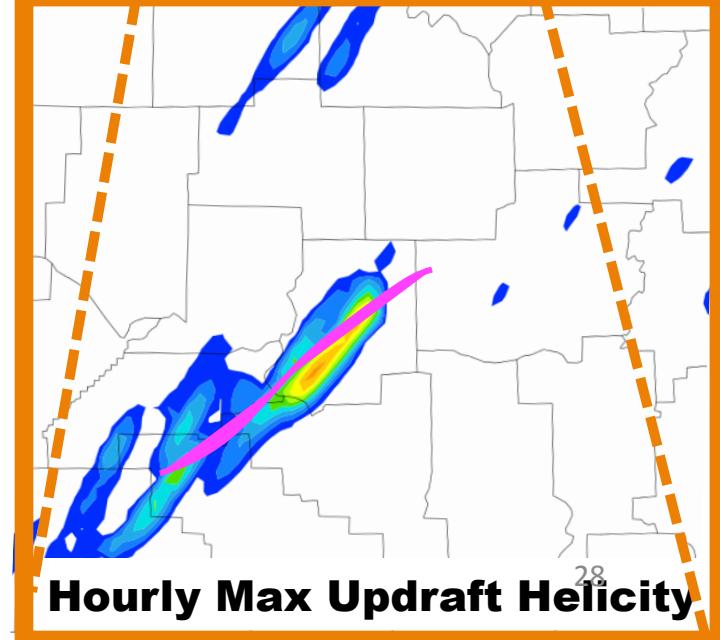
HRRR
10-hr fcst
made
at 10 AM
for 8 PM
27 April



Forecast Reflectivity

The 10-hour forecast captures the exact location of the storm and indicates the potential for rotation.

○ Tornadic
thunderstorm
— Actual
tornado path



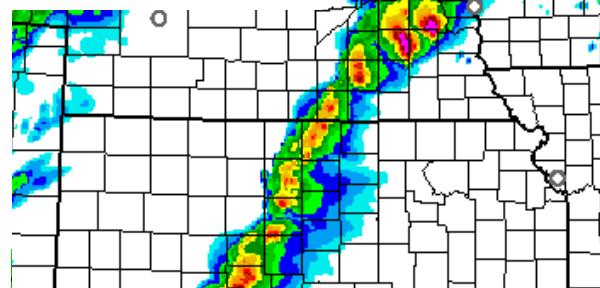
Hourly Max Updraft Helicity

Run-to-Run Consistency

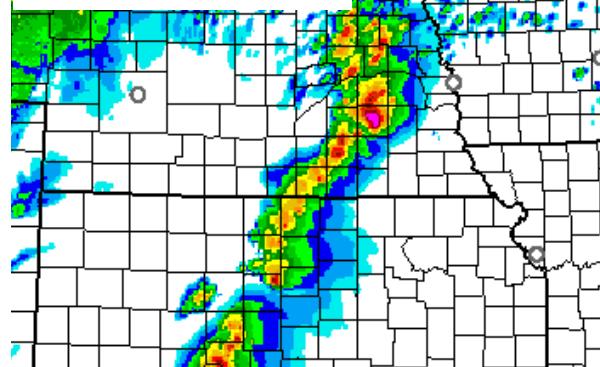
HRRR Forecasts
valid at 2200 UTC

Radar Obs at 2200 UTC

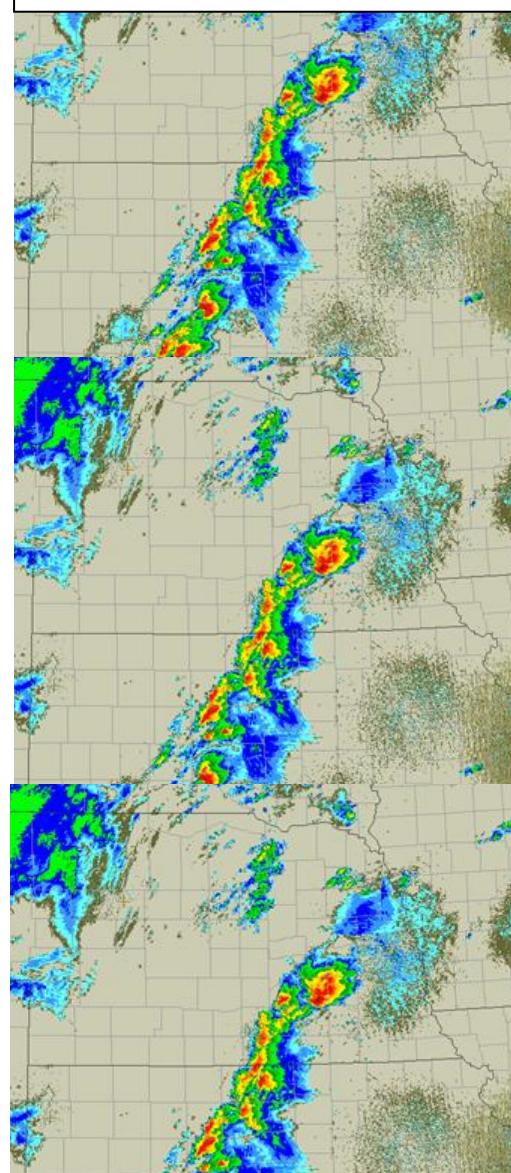
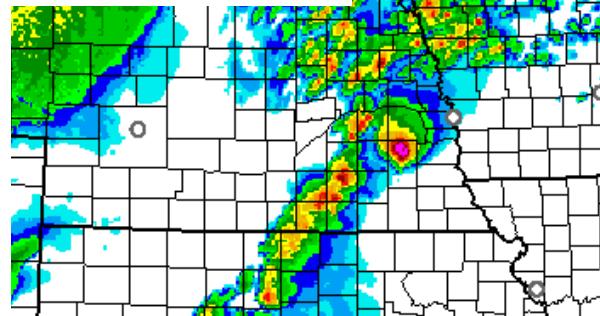
15 UTC (7hr)



16 UTC (6hr)

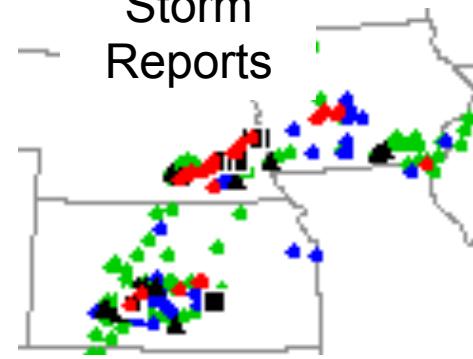


17 UTC (5hr)

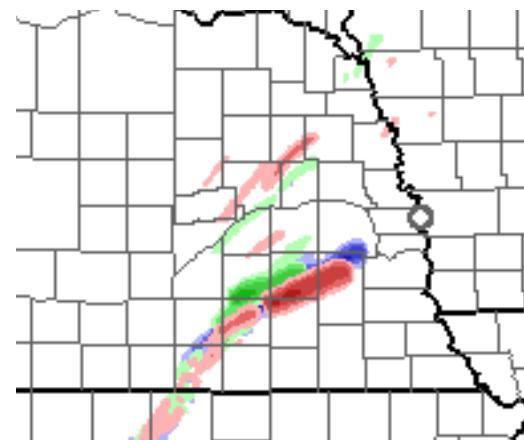


11 May 2014

Storm
Reports



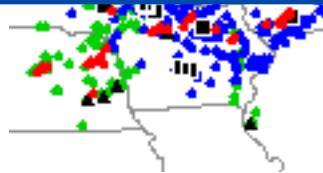
Updraft Helicity
Time-Lagged Ensemble



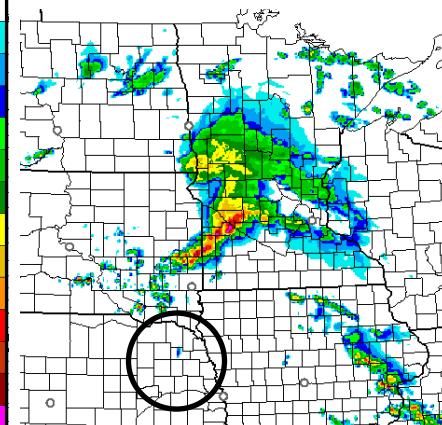


HRRR Run-to-Run Trend

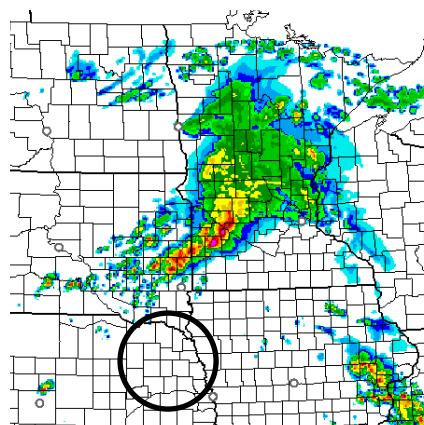
Storm Reports



14 UTC (7hr)

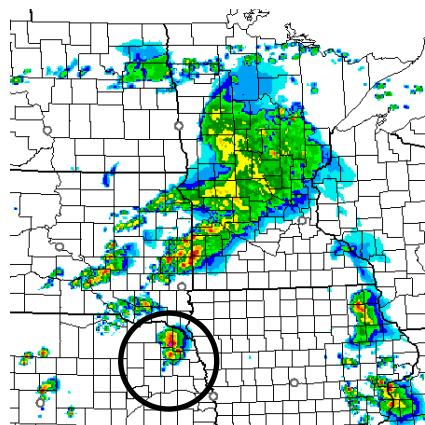


15 UTC (6hr)

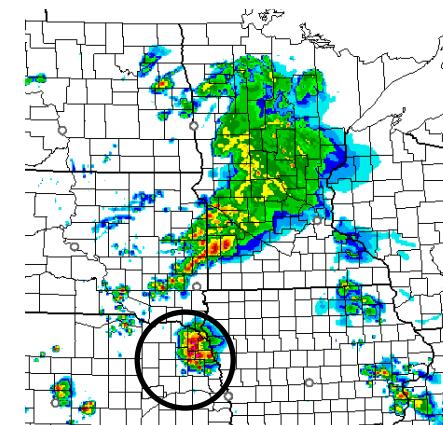


16 June 2014 Pilger, NE

16 UTC (5hr)

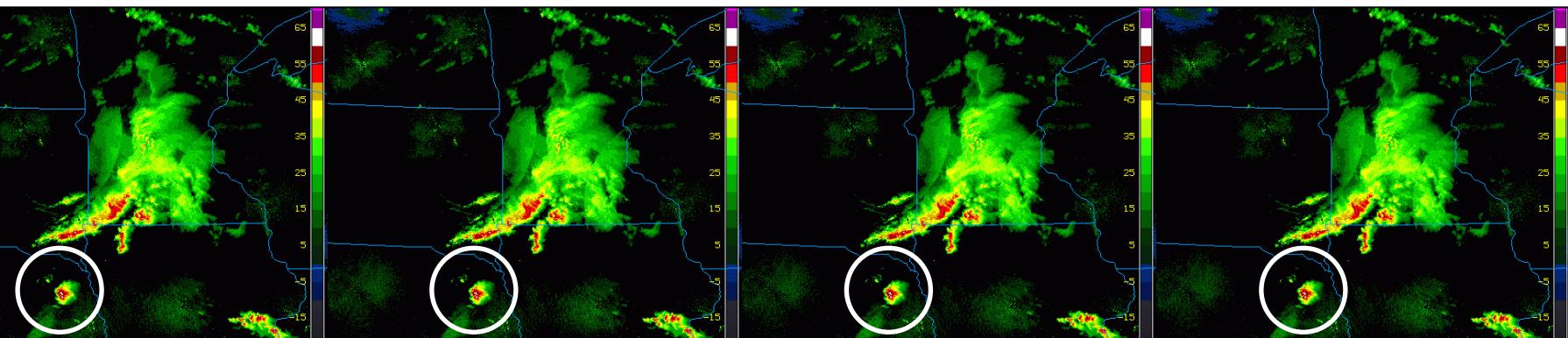


17 UTC (4hr)



HRRR Forecasts: valid at 2100 UTC

Radar Obs at 2055 UTC





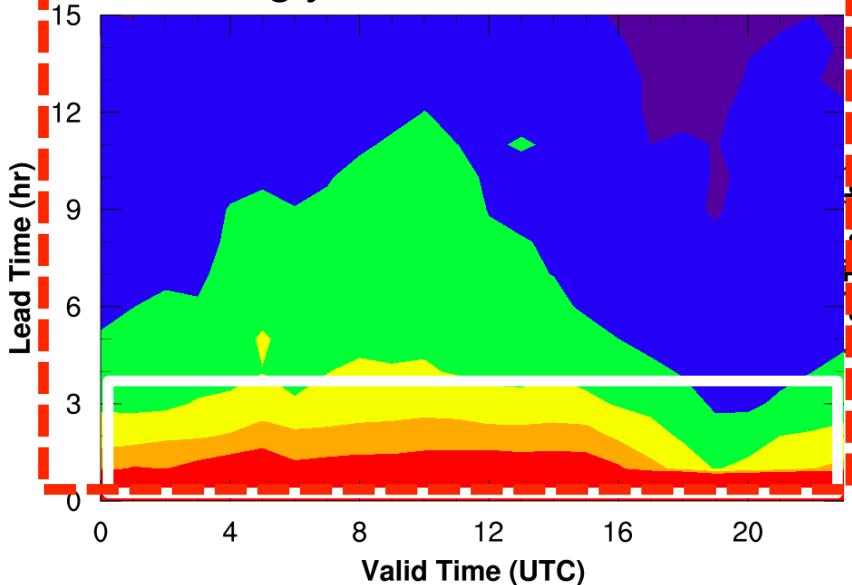
Summary of HRRR Forecast Skill

Average CSI for Reflectivity $\geq 35 \text{ dBZ}$

Stats for east of
100°W longitude
(good radar coverage
for verification)

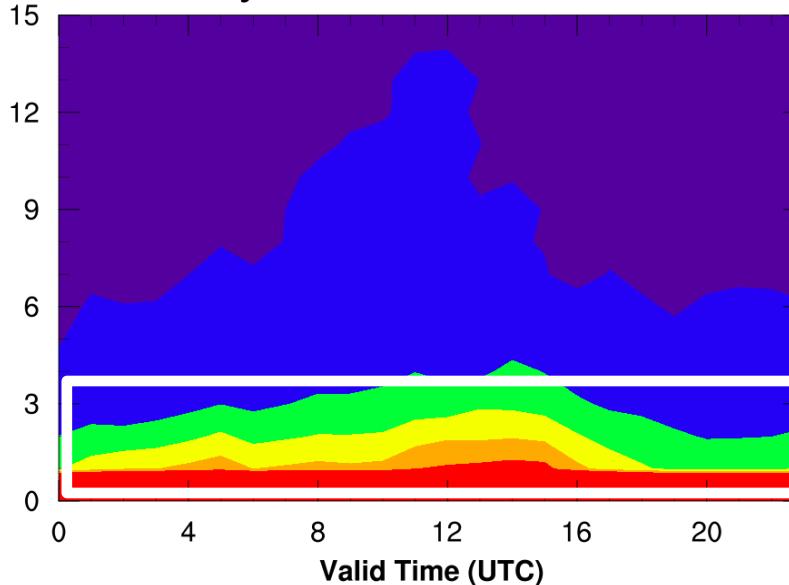
Spring (Apr-June)

Strongly forced environments



Summer (July-Sept)

Weakly forced environments



More skill at short lead times.
More skill in evening and overnight hours.
More skill in strongly forced environments.



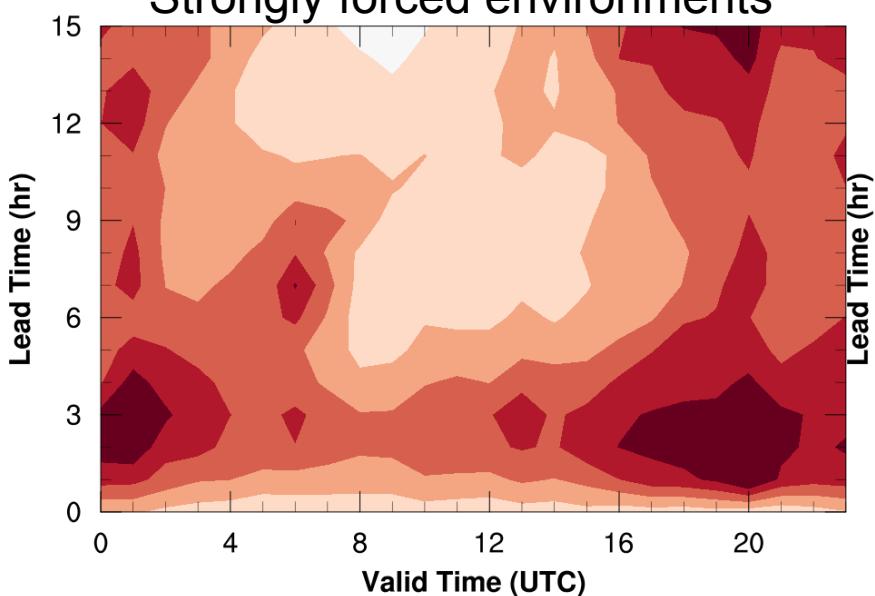
Summary of HRRR Forecast Skill

Average BIAS for Reflectivity ≥ 35 dBZ

Stats for east of
100°W longitude
(good radar coverage
for verification)

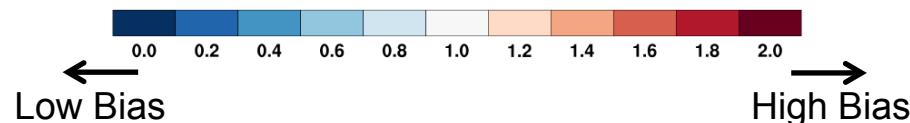
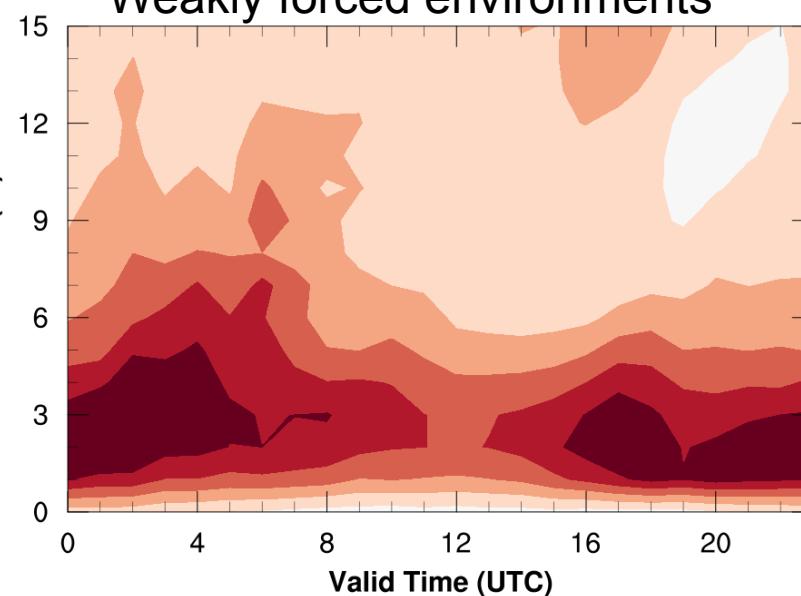
Spring (Apr-June)

Strongly forced environments



Summer (July-Sept)

Weakly forced environments



Higher bias at early lead times



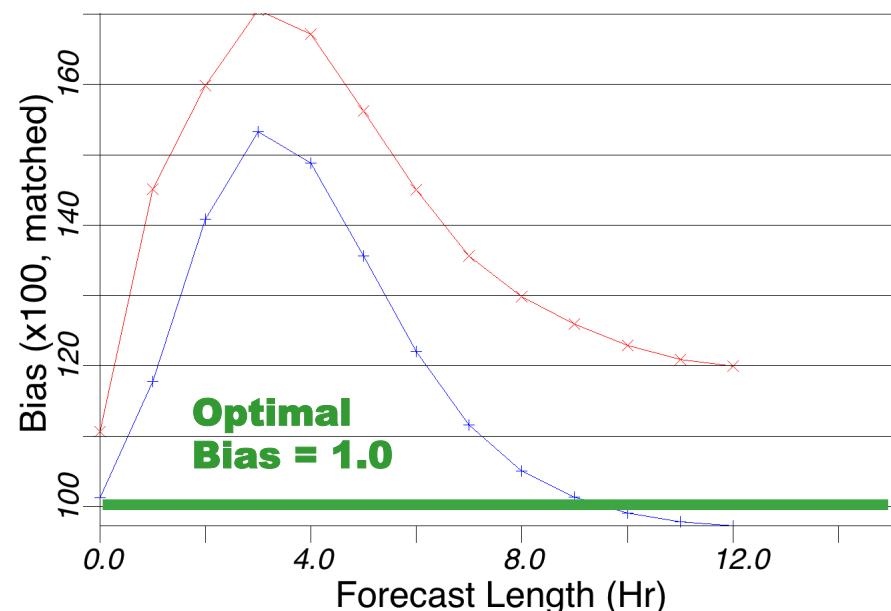
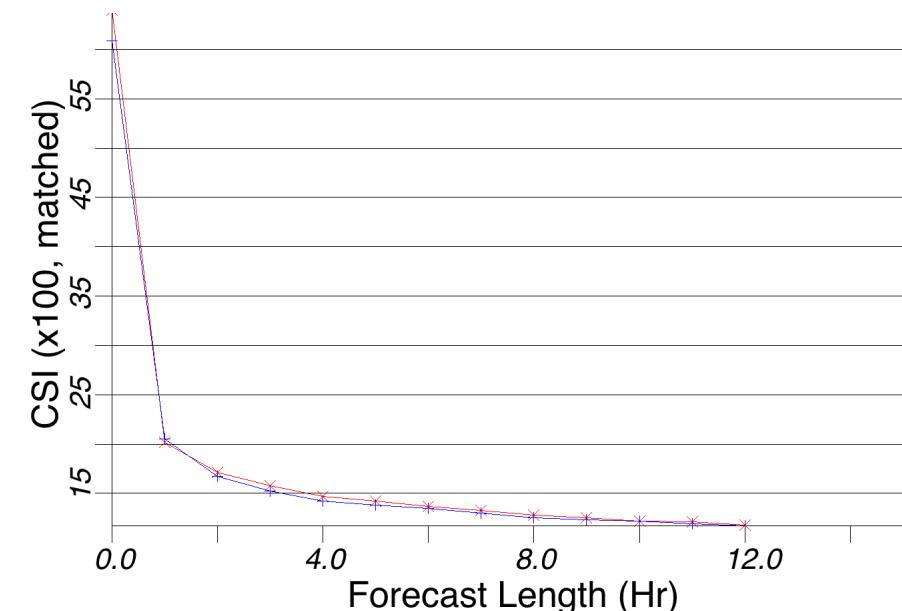
HRRRv1 vs HRRRv2

30 dBZ Composite Reflectivity
Eastern US Aug-Sep 2014

HRRR-OPER (v1) HRRR-EXP (v2)

40 km CSI

03 km BIAS

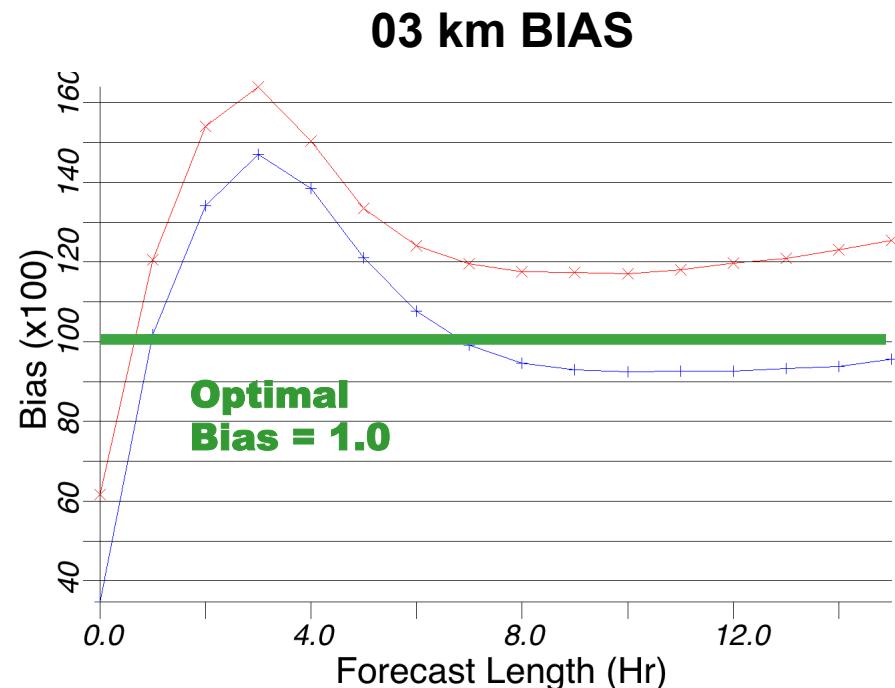
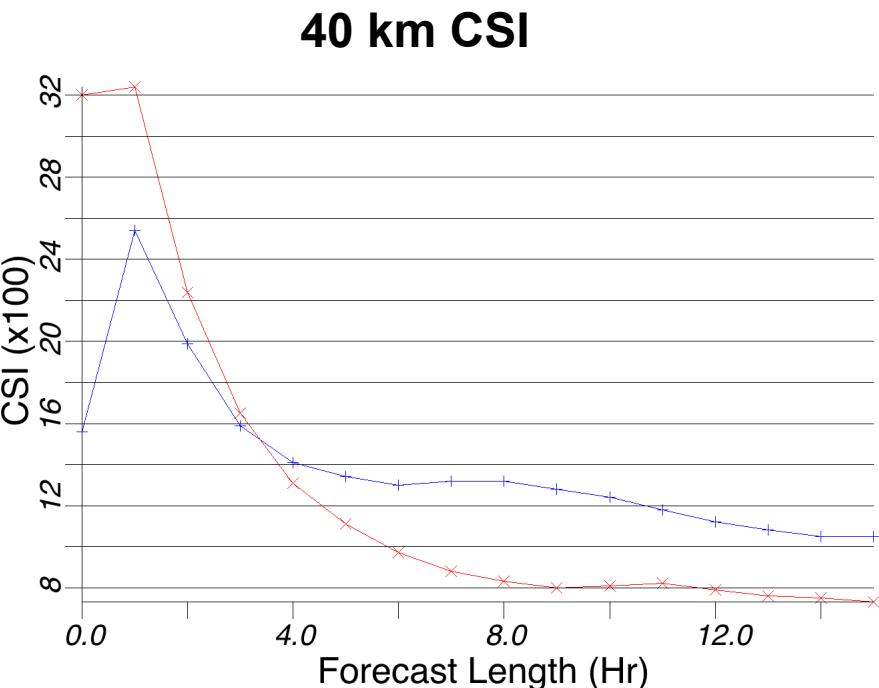


Improved bias at all lead times



HRRR 2013 (v1) vs HRRR 2014 (v2)

25 kft 18 dBZ Echo Tops
Northeastern US May – Sept
- 2013 - 2014



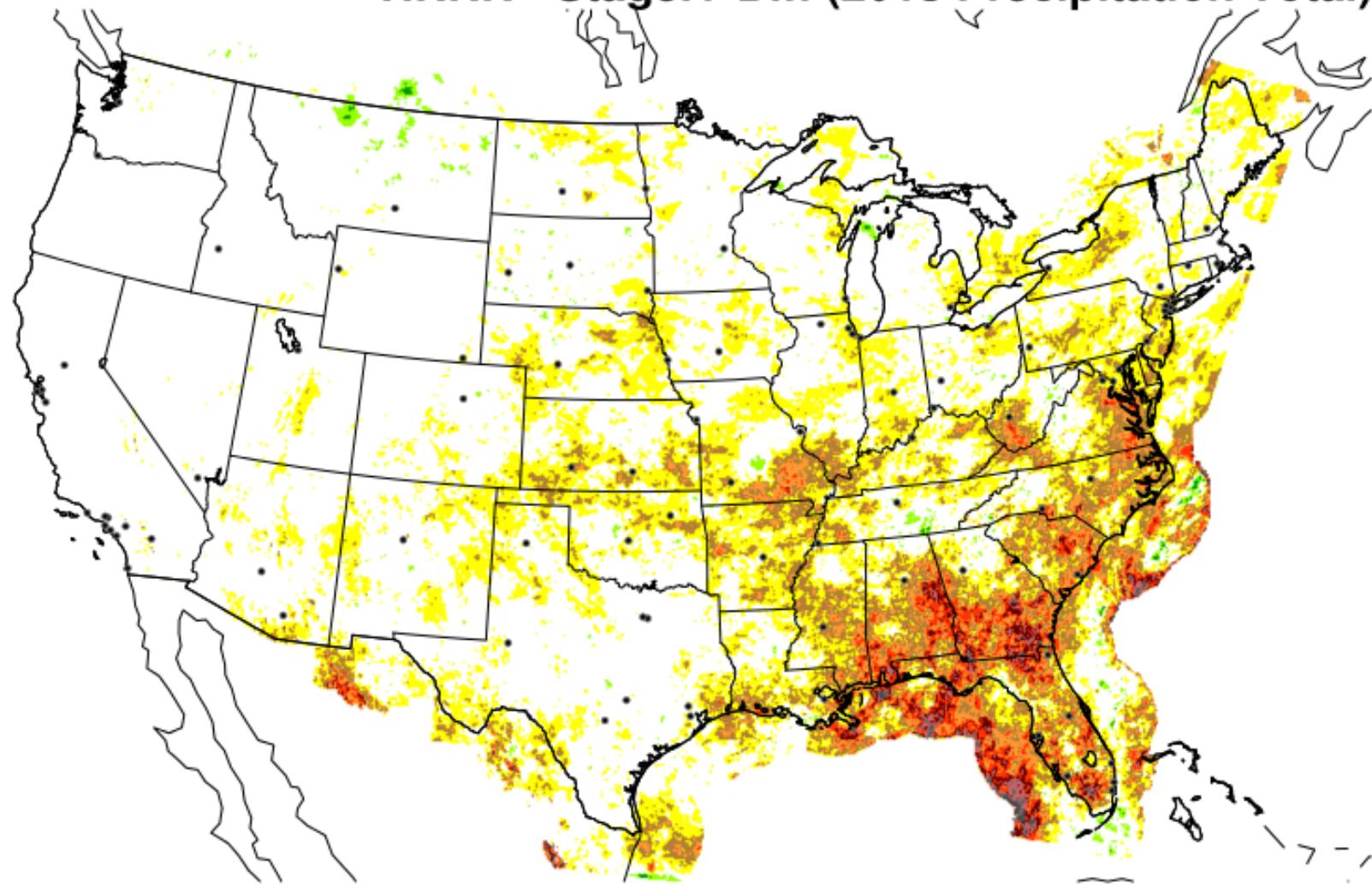
Improved skill at ~2+ forecast hrs



HRRR Precipitation Bias 2013 (v1)

HRRR 6h fcsts from 01JUN - 31AUG 2013

HRRR - StageIV Diff (2013 Precipitation Total)

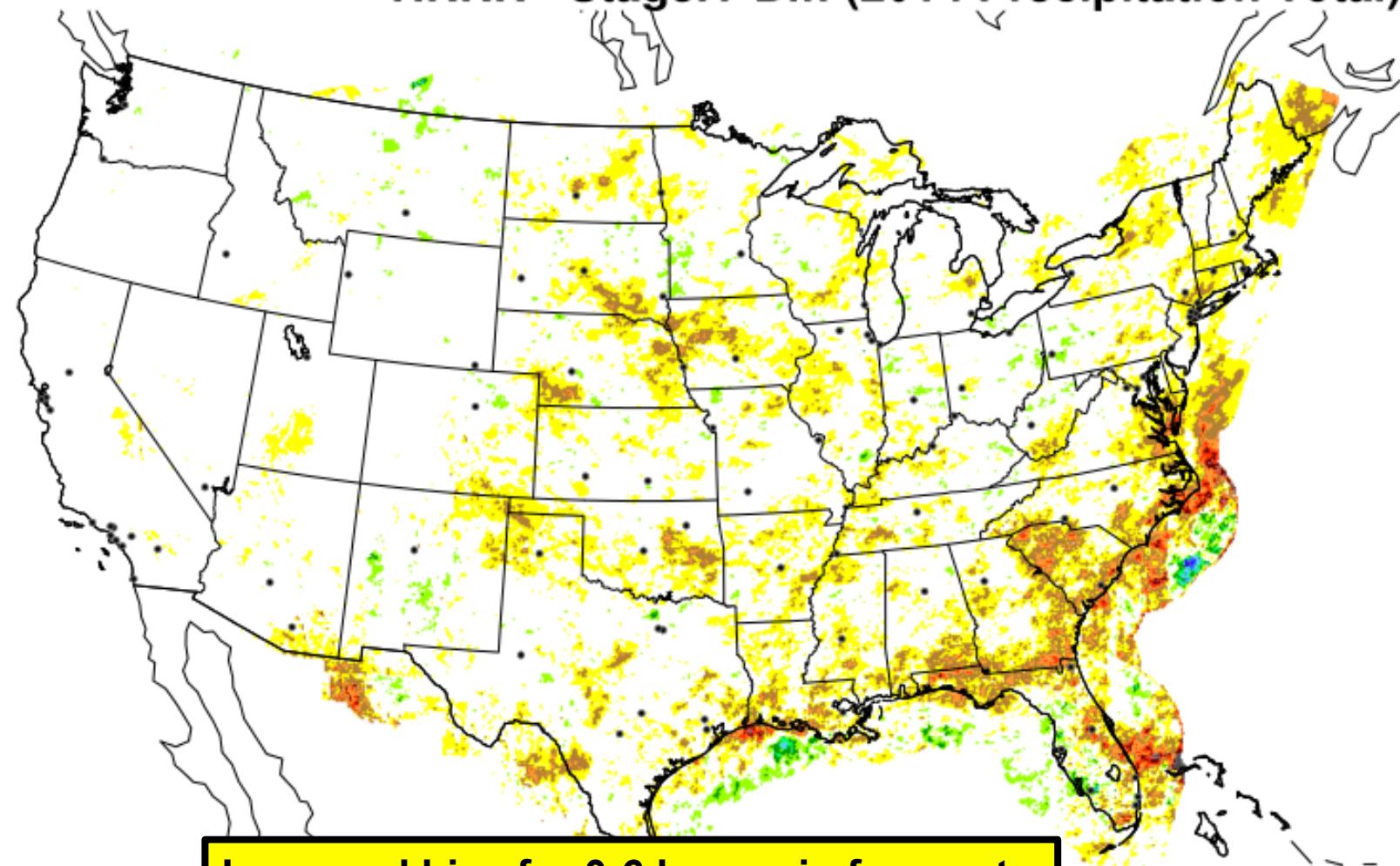




HRRR Precipitation Bias 2014 (v2)

HRSS 6h fcsts from 01JUN - 31AUG 2014

HRSS - StageIV Diff (2014 Precipitation Total)

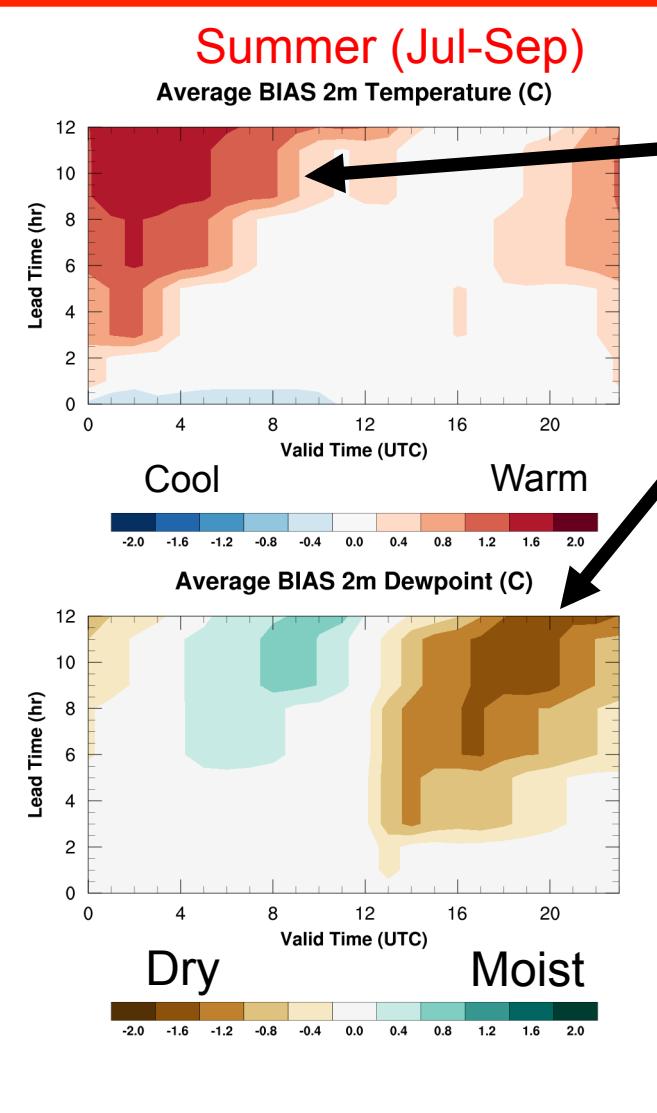
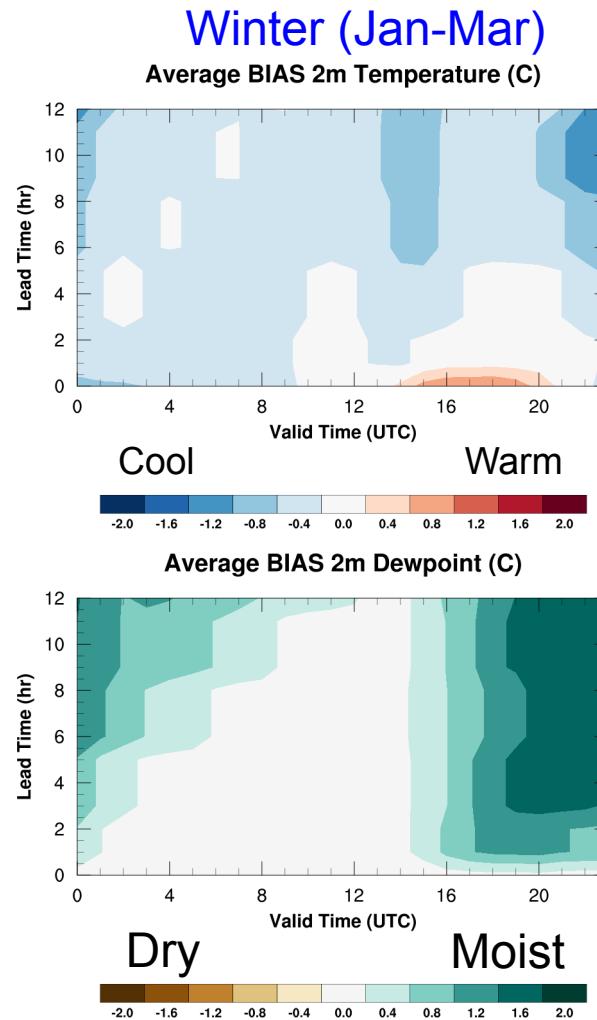


Improved bias for 0-6 hr precip forecasts





HRRR Forecast Biases



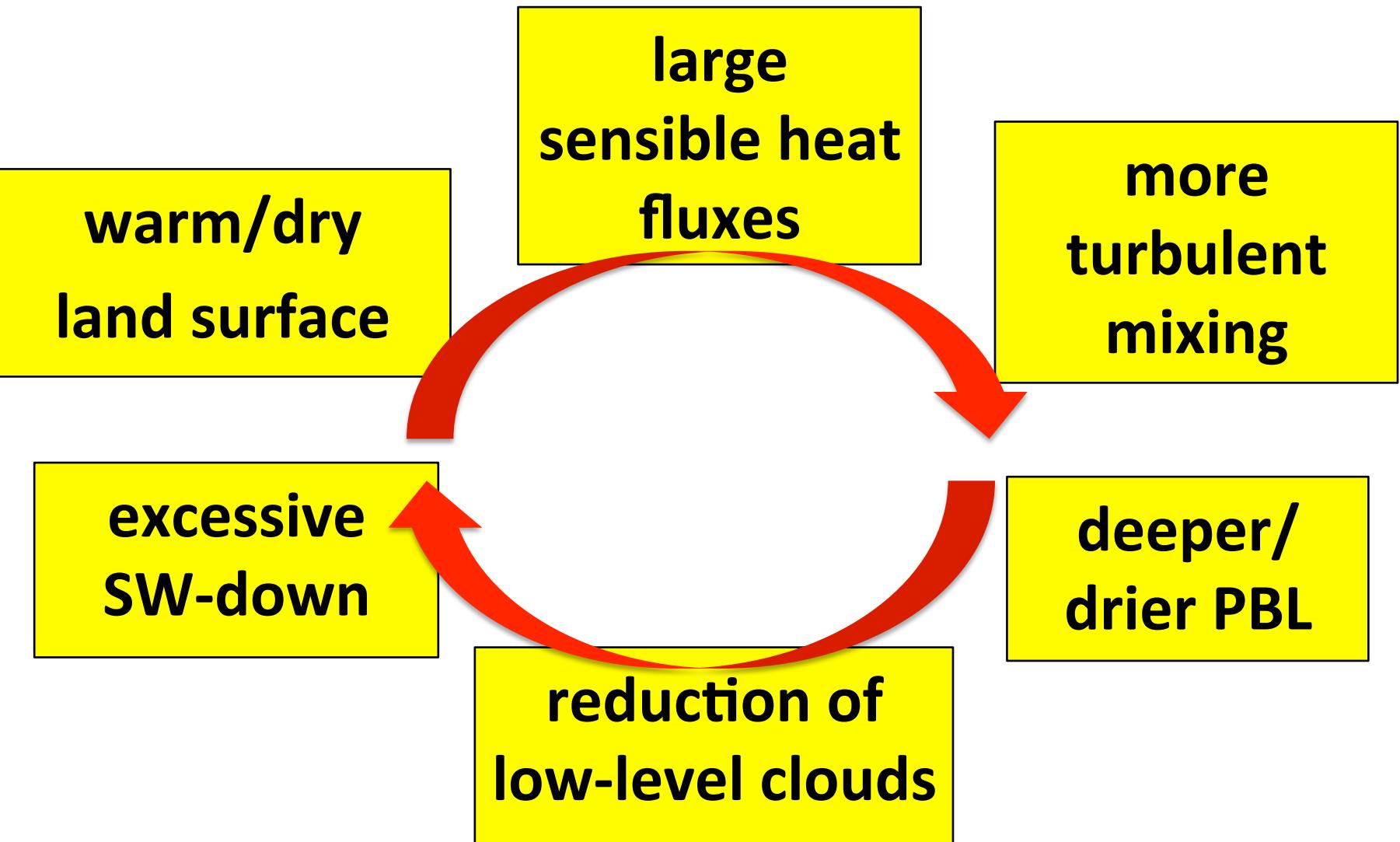
The HRRR has a daytime warm bias in the warm season.

The HRRR has a daytime dry bias in the warm season.

Experimental improvements to the model to remove bias have been made and will be implemented in a future version.



RAP/HRRR Model Bias Feedback





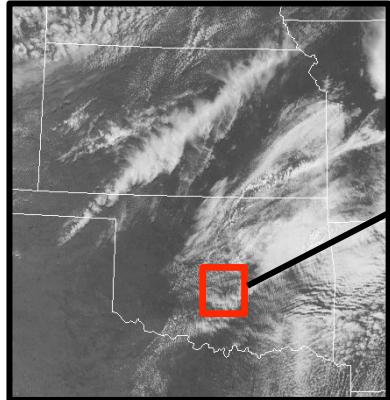
HRRR Model Warm/Dry Bias Mitigation

Component	Items
GSI Data Assimilation	Canopy water cycling Temp pseudo-innovations thru model boundary layer More consistent use of surface temp/dewpoint data
GFO Convective Parameterization	Shallow cumulus radiation attenuation Improved retention of stratification atop mixed layer
Thompson Microphysics	Aerosol awareness for resolved cloud production Attenuation of shortwave radiation
MYNN Boundary Layer	Mixing length parameter changed Thermal roughness in surface layer changed Coupling boundary layer clouds to radiation
RUC Land Surface Model	Reduced wilting point for more transpiration Keep soil moisture in croplands above wilting point

Total Resource Change: Approximately ~6% increase in runtime for aerosols



Model Warm/Dry Bias Mitigation

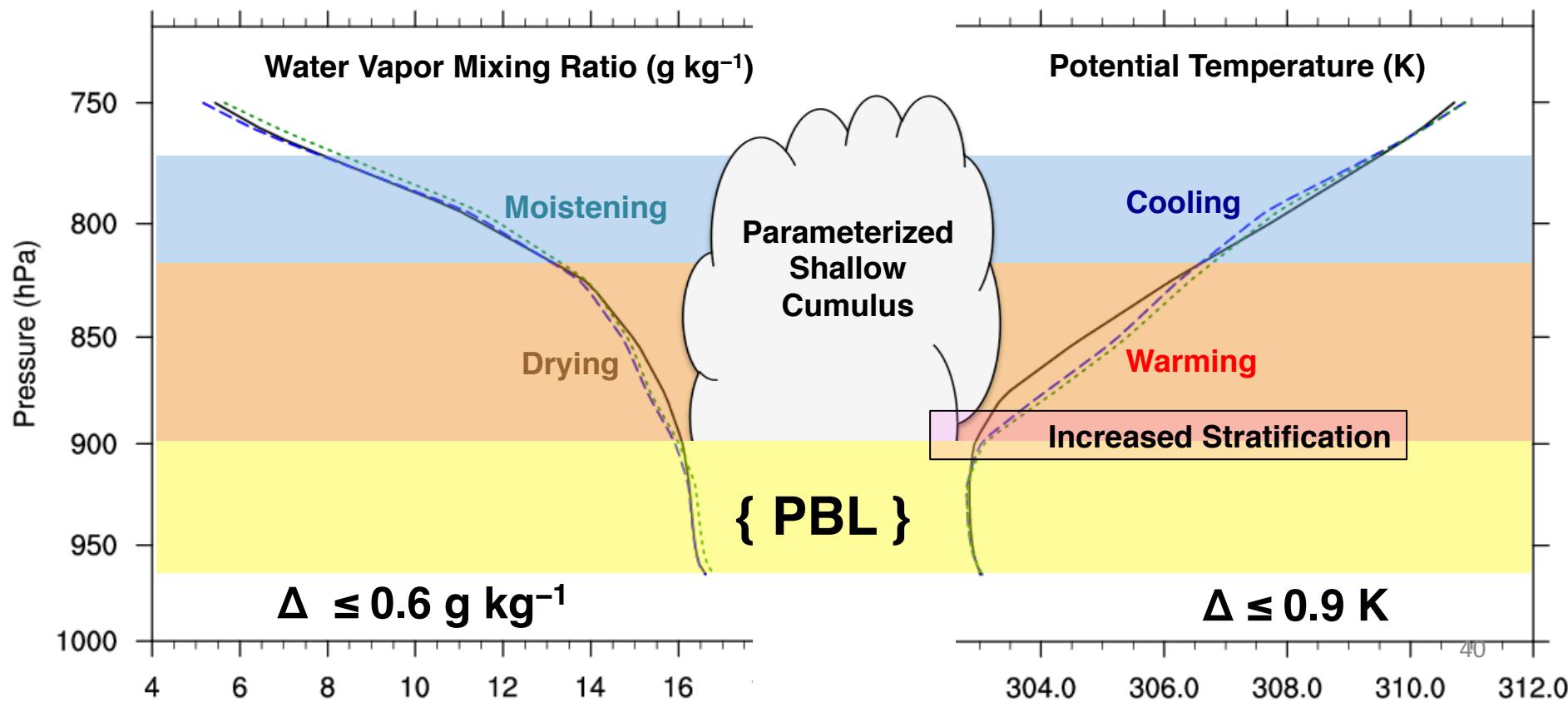


area mean (437 grid points)
8-h forecasts valid 1700 UTC
20 May

Control —

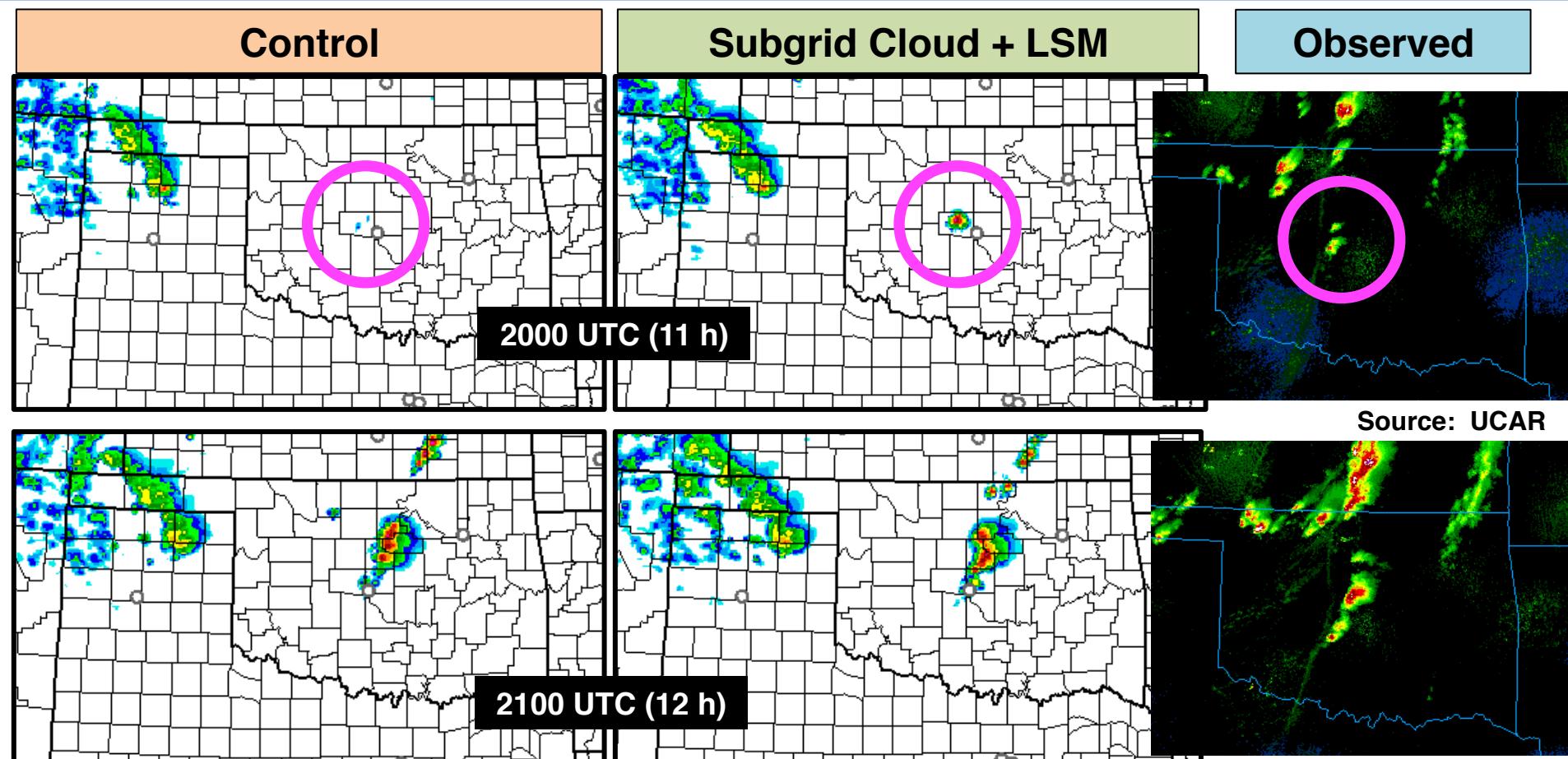
Subgrid Cloud - - -

Subgrid Cloud + LSM - - - -

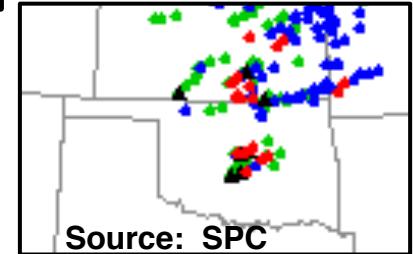




Convective Initiation 19 May 2013



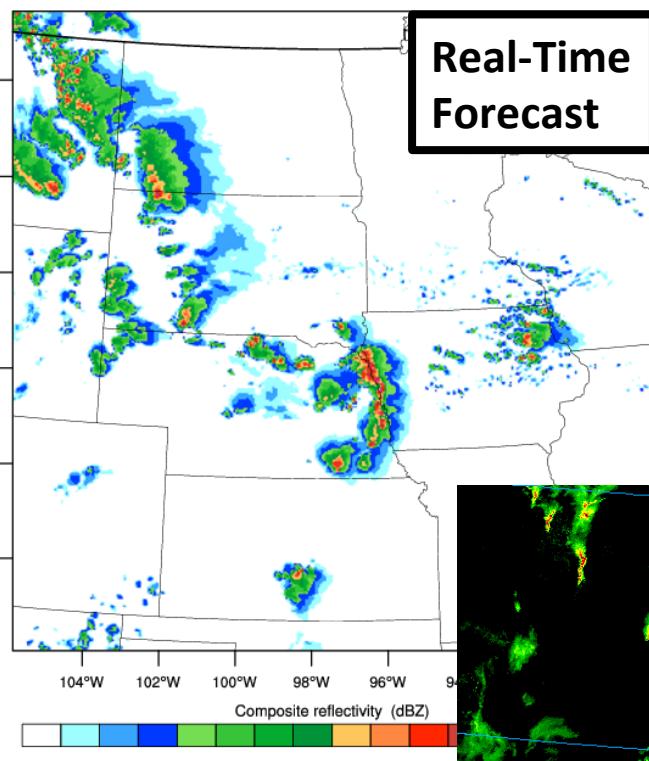
Control run depicts initiation ~1-h too late
Model Physics Changes improving timing of CI





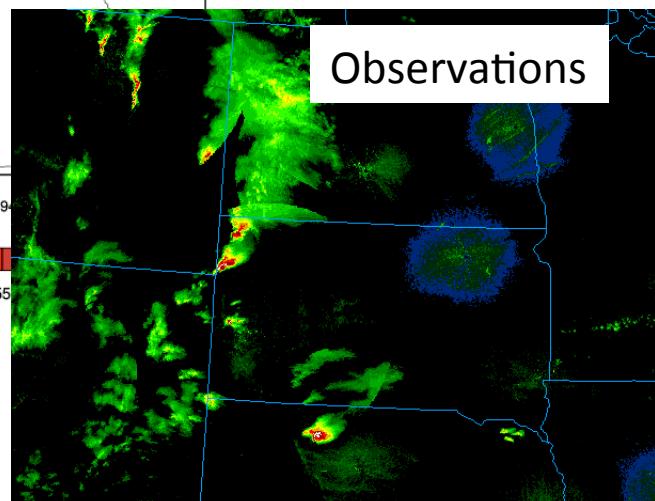
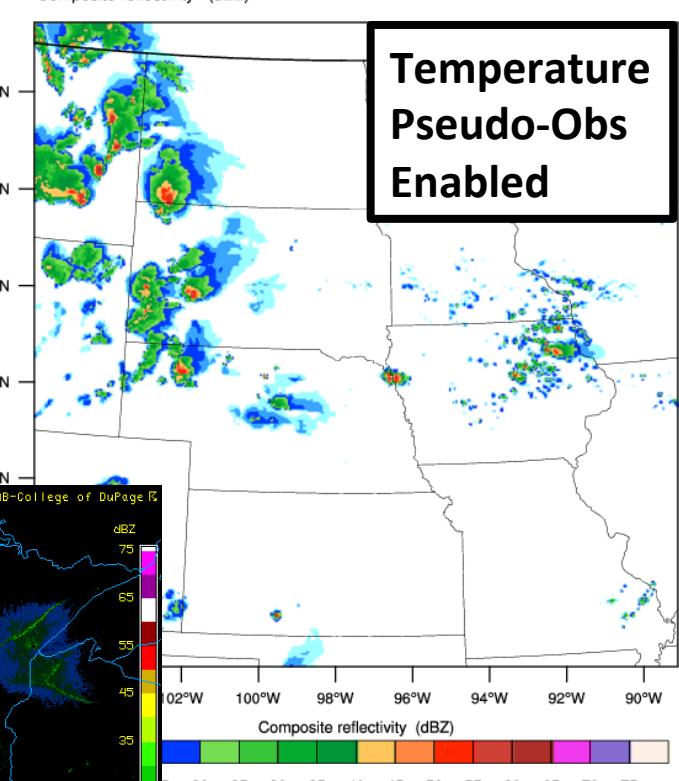
Convective Evolution 17 June 2014

Composite reflectivity (dBZ)



00 UTC
18 June 2014
Coleridge, NE

Composite reflectivity (dBZ)



Control run develops too much high-based convection that grows upscale
Data assimilation change improves timing and evolution of convection



RAP and HRRR Precip Type

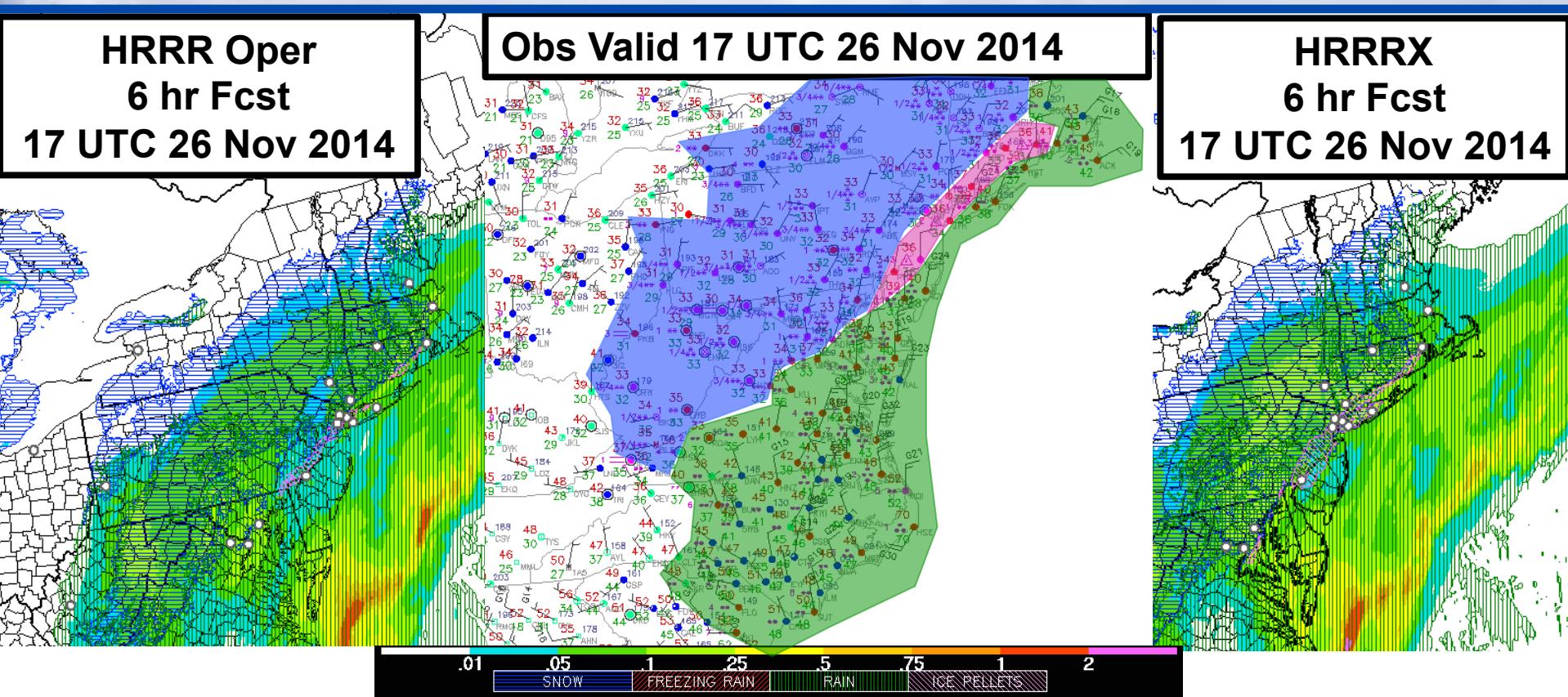
HRRR Oper
6 hr Fcst

17 UTC 26 Nov 2014

Obs Valid 17 UTC 26 Nov 2014

HRRRX
6 hr Fcst

17 UTC 26 Nov 2014

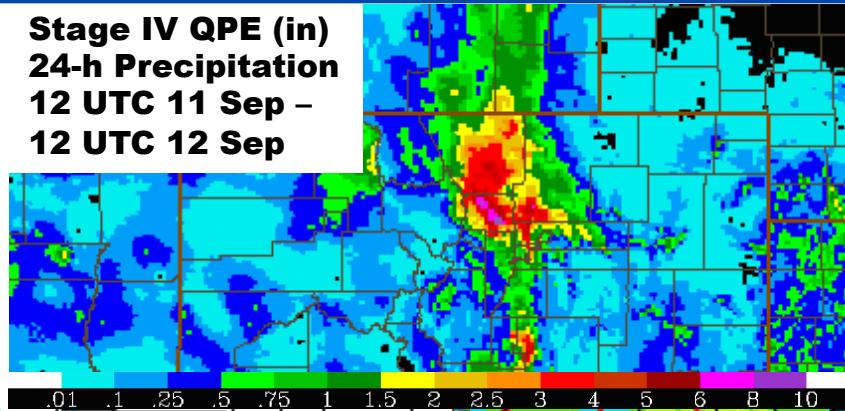


**HRRR Resolves
Narrow Band of IP
With Improved Diagnostic**

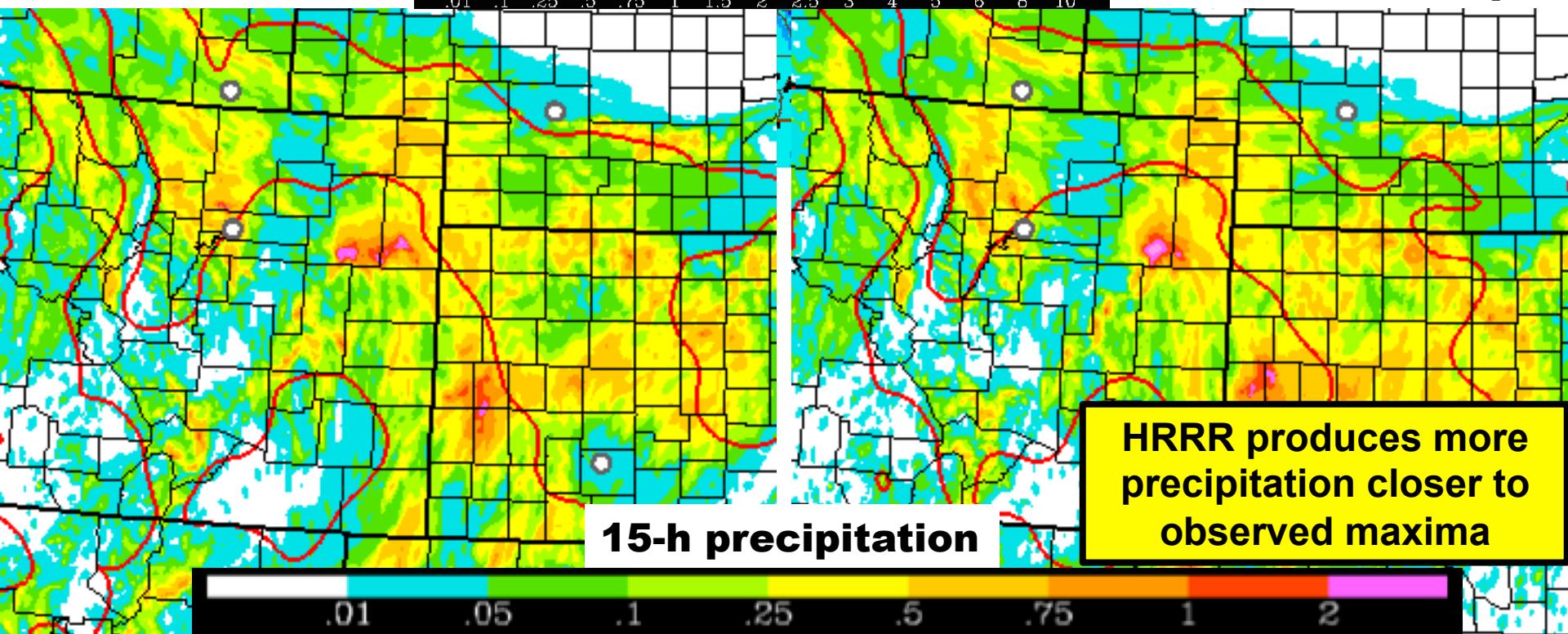


HRRR Radar DA Research

Control Run
Init 18z 11 Sep
Valid 09z 12 Sep



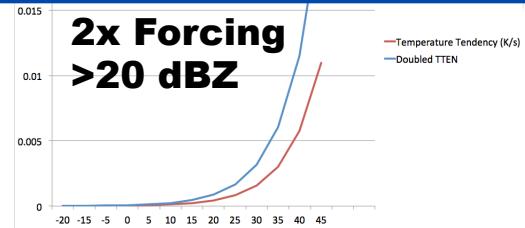
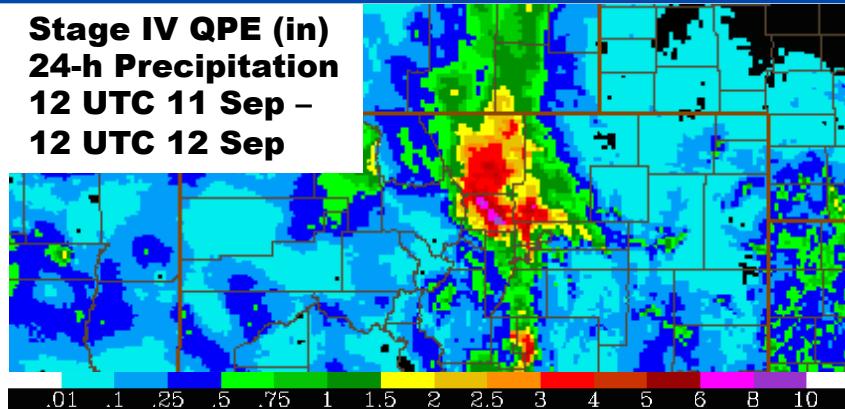
“Warm Rain”
Init 18z 11 Sep
Valid 09z 12 Sep



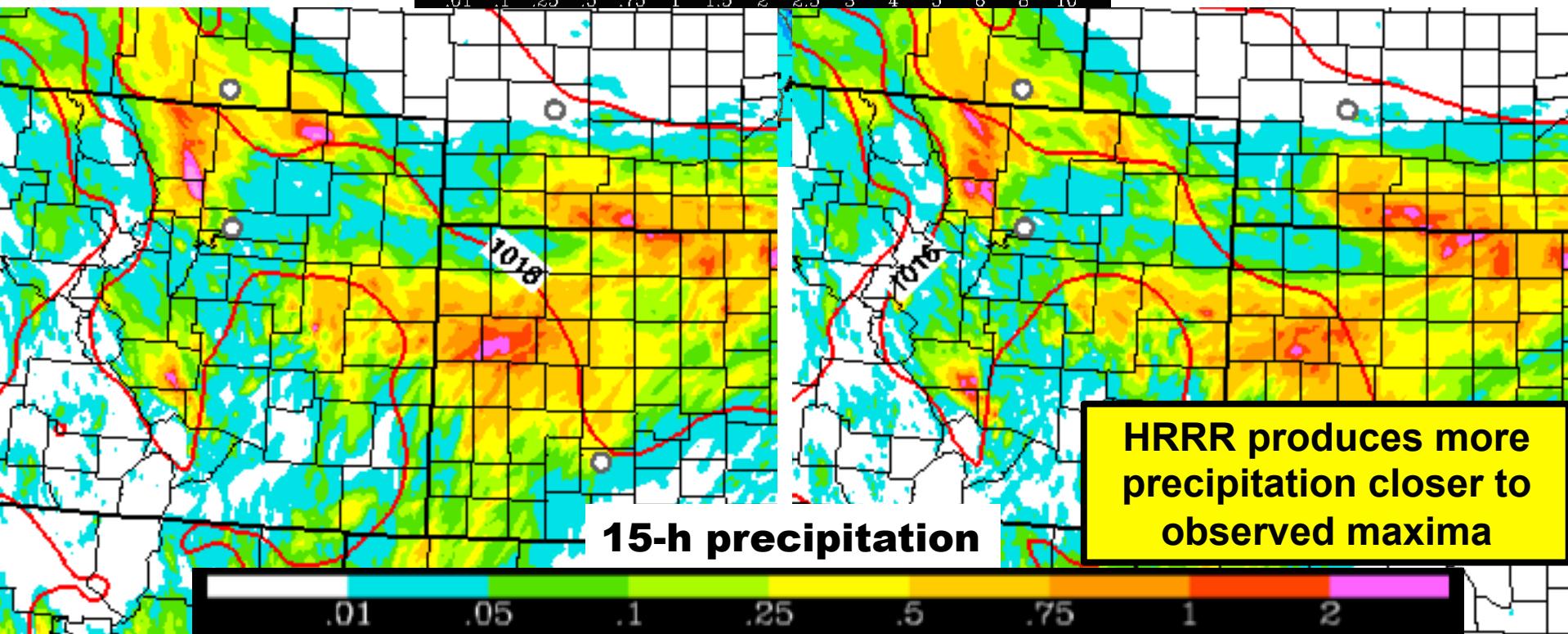


HRRR Radar DA Research

Control Run
Init 18z 11 Sep
Valid 09z 12 Sep



“Warm Rain”
Init 18z 11 Sep
Valid 09z 12 Sep





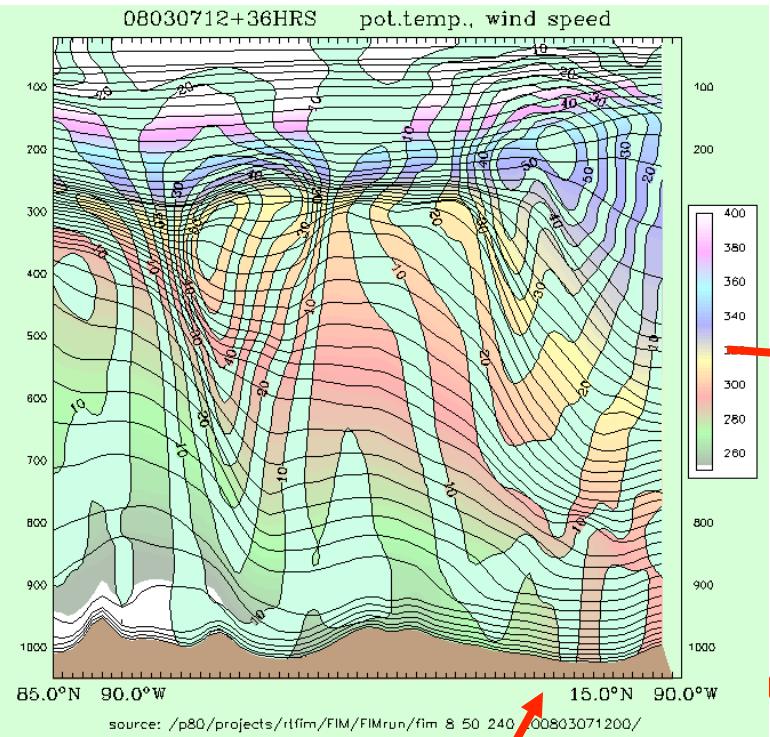
RAP/HRRR Implementation Map

ESRL – experimental version

- **RAPv3 – GSD testing in 2014**
 - Will initialize 2014 ESRL-HRRR(v2)
 - Improved PBL, LSM, cu-parm, DA
 - WRFv3.6.1 w/ Thompson/NCAR aerosol-aware microphysics
- **HRRRv2 – GSD testing in 2014**
 - Initialized by 2014 RAP (v3)
 - Improved radar assimilation, hybrid assimilation, PBL/cloud physics
- **RAPv4 – GSD testing in 2015**
 - Hourly RAP ensemble data assimilation
- **HRRRv3 – GSD testing in 2015**
 - Target: Improved 3km physics + improved data assimilation.

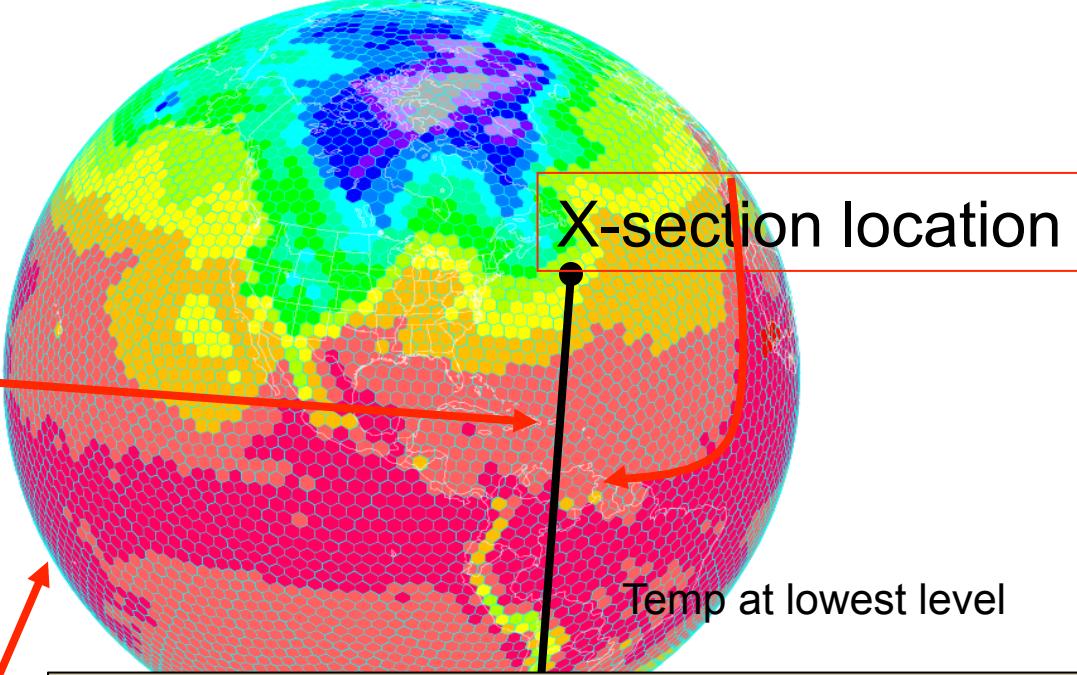
NWS-NCEP - operational

- Implement Q3 2015
- Implement Q3 2015
- Implement 2016
- Implement 2016



Flow-following- finite-volume icosahedral Model FIM

<http://fim.noaa.gov>



**Sandy Supplemental funded
*High-Impact Wx Pred Proj
(HIWPP)* - Year 2 exp demo**

- Exp FIM13km, NAVGEM23, GFS13
- ESRL/NCEP eval of exper multi-model ensemble -GFS and FIM (10 members each)
- Note: FIM uses NEMS, GFS physics, fits within NEMS global framework.



Work Flow: HIWPP Hydrostatic Model Data

Real-time research mode from Jan-Dec 2015

Model	Output
FIM-13km – GFS physics	1/8 deg, hourly
FIM-13km – research (2) – GF cumulus	1/8 deg, hourly
GFS-T1534 (1)	1/4 deg, 3h
NAVGEM-23km-experimental - (1)	1/4 deg, 3h
FIM-GFS experimental ensemble	Coarse res, 6-hrly, 10 FIM members

2015 evaluation and forecasts under HIWPP
• Tim Schneider

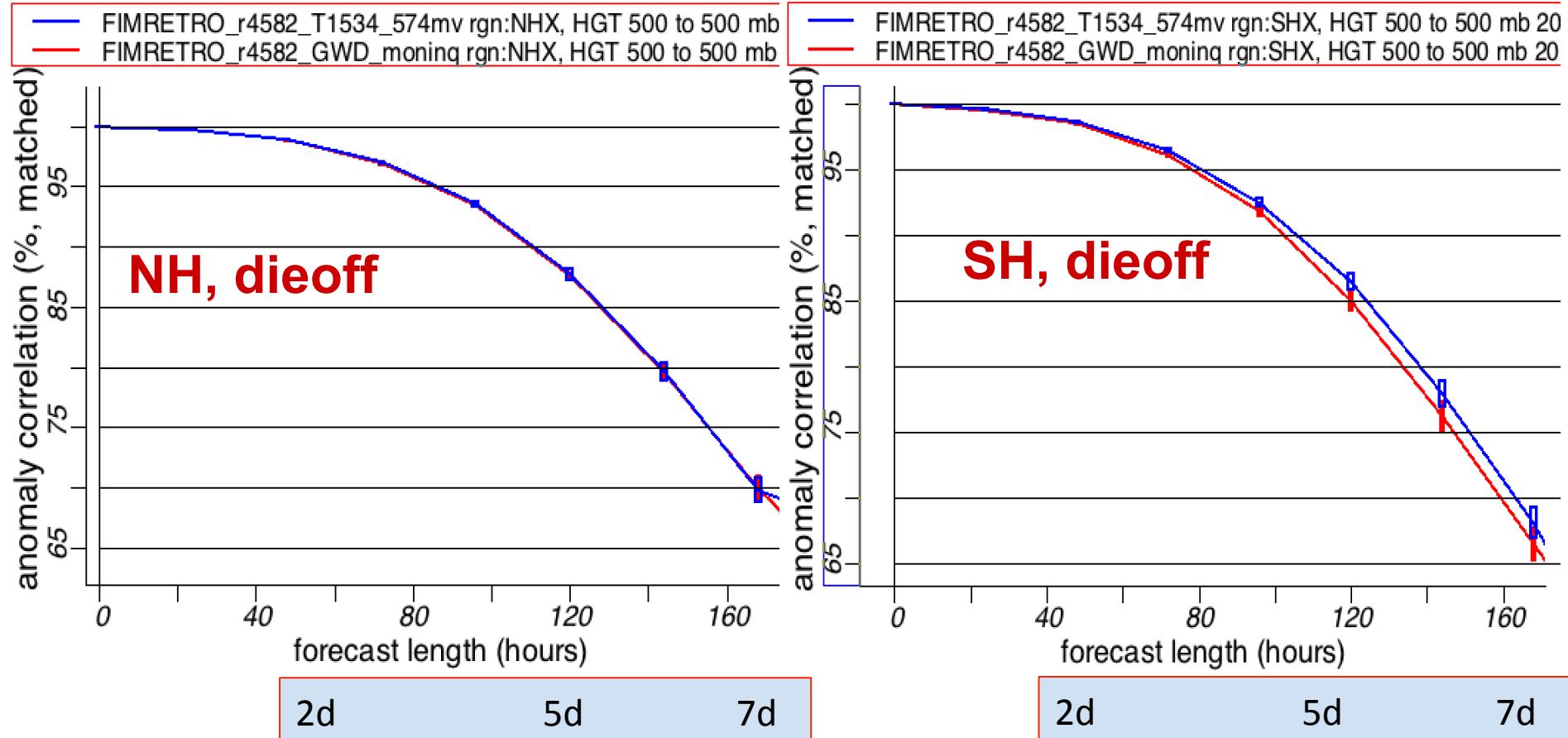
Effect of Improved GFS Initial Conditions

500-hPa Height Anomaly Correlation

FIM-30km (GFS phys)

GFS T574 IC vs. T1534 IC

12-month test
Oct 2013 -Sept 2014



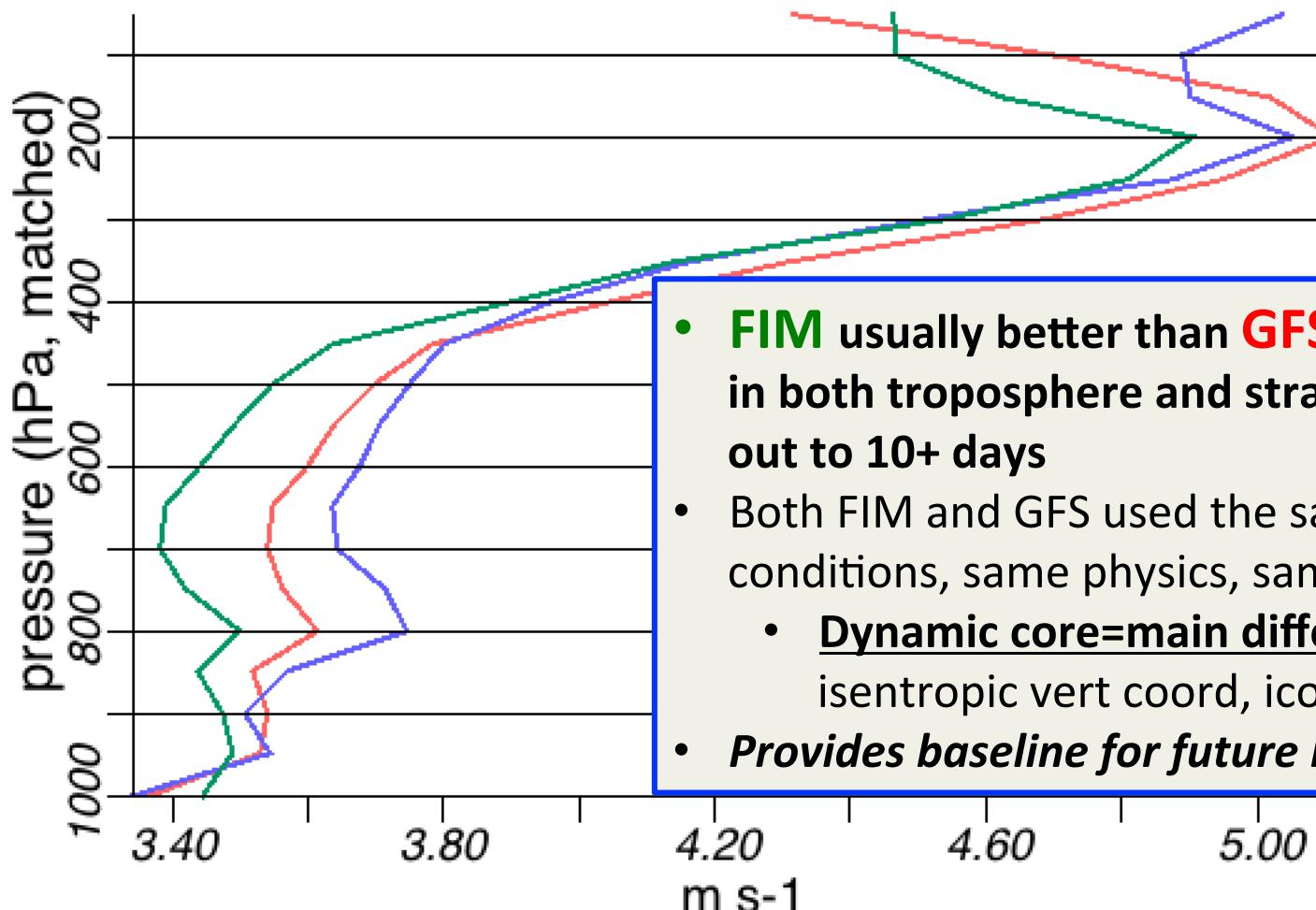
New T1534-GFS init conditions results in 1.5 pts better 500hPa ACC in S. Hemis, about zero impact in N. Hemis.

FIM model provides independent test to isolate analysis effect

CONUS – 12h Vector Wind RMSVE

FIM vs. GFS vs. HRRR vs. raobs – Jul-Nov 2014

- FIM_prs rgn:RUC, winds rms 12h fcst 2014-06-30 thru 2014-12-02
- HRRR_iso rgn:RUC, winds rms 12h fcst 2014-06-30 thru 2014-12-02
- GFS rgn:RUC, winds rms 12h fcst 2014-06-30 thru 2014-12-02



- FIM usually better than GFS for wind forecasts in both troposphere and stratosphere from 12h out to 10+ days
- Both FIM and GFS used the same hybrid initial conditions, same physics, same res
 - Dynamic core=main difference (quasi-isentropic vert coord, icosahedral horiz grid)
 - *Provides baseline for future NGGPS evaluation*

ESRL Global Model Development

- HIWPP – hydrostatic real-time demo
 - FIM15km – 1/8 deg to 14 day, NAVGEM-23km, GFS
 - Ensemble – FIM40km (GFS phys + Grell-Freitas) as experimental contribution to GEFS
- HIWPP – non-hydrostatic core – NGGPS dycore candidate
 - **NIM** – ESRL icosahedral – real-data, optimization development/testing
- Coupled model development
 - Testing of **FIM-HYCOM coupled** model toward experimental week 3-4 and NMME applications.
- Physics
 - Scale-dependent **Grell-Freitas conv scheme** (2013, ACP) is being tested from **6-hour** forecasts (part of RAPv3) through **NWP** application (FIM) to **coupled/seasonal** model application (FIM-HYCOM), also in testing in MPAS for NWP

Evolution of hourly updated NOAA modeling

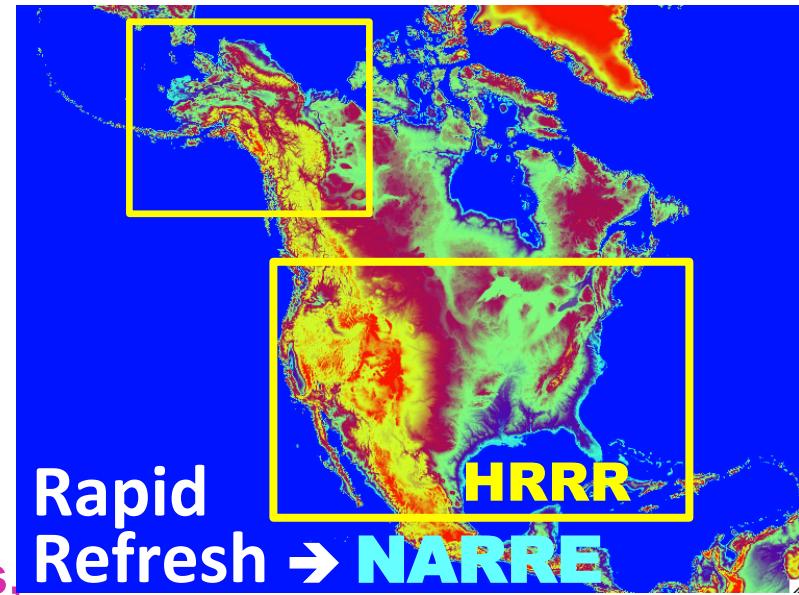
Feb 2014 – **Rapid Refresh v2** – oper at NCEP

Sep 2014 – **HRRR v1** – oper at NCEP

2015 – **RAPv3 and HRRRv2** – est. June impl.

- Model – improved physics – MYNN PBL / LSM/snow, aerosol-aware cloud physics numerics improvements, updated WRF
- Assimilation – radar assim for light precip, lightning, 2m T/Td forward model, rad wind

→ Improved surface/lower trop forecasts, convective environment, clouds



Future oper @ NCEP

2016 – **RAPv4/HRRRv3**

2017 – **Ensemble Rapid Refresh/NAM – NARRE**
(w/ hybrid 4d-ens/var DA)

2019? – **Ensemble HRRR**
– **HRRRE** – (ultimately with hourly ~3km ensemble DA)

North American Rapid Refresh Ensemble

- NMMB, ARW cores
- Hourly updating with GSI-hybrid EnKF (4DEnVar?)
- Initially 6 members, 3 each core, physics diversity (stochastic only or with RAP/NAM/NCAR physics suites)
- Hourly forecasts to 24-h
- NMMB +ARW members to 84-h 4x/day